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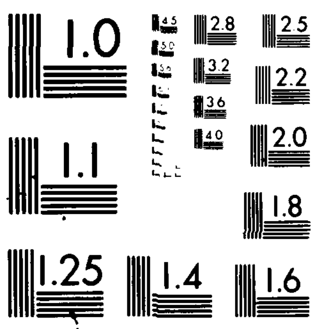

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BLAST/FIRE INTERACTIONS

Asilomar Conference
May 1980

Proceedings of the Conference

Prepared for:

FEDERAL EMERGENCY MANAGEMENT AGENCY
Office of Mitigation and Research
Washington, D.C. 20472

Attention: Dr. David W. Bensen, COTR

Contract No. DCPA01-78-C-0279
DCPA Work Unit 2563F

SRI Project PYU 7814
(Published Feb. 1981)

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BLAST/FIRE INTERACTIONS

Asilomar Conference

Proceedings of the Conference

Edited by: Raymond S. Alger
Stanley B. Martin

Prepared for:

FEDERAL EMERGENCY MANAGEMENT AGENCY
Office of Mitigation and Research
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(Published Feb. 1981)

Approved by:

G. R. Abrahamson, Vice President
Physical Sciences Division

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Blast responses of urban elements

Fire spread, fire dynamics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the proceedings of the FEMA-sponsored ~~conference on~~ blast/fire-interaction research, held May 18 through 21, 1980, at Asilomar, California. This conference, the third of an annual series, convened a selected group of authorities on fire effects, airblast effects, structural responses, and related technologies to reassess the significance of this nuclear-attack problem area and evaluate the contributions that ongoing studies are making, and proposed research could add, to alleviate the technical

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deficiencies which limit analytical progress. A continuing research program to upgrade the state of art at a rate consistent with national priorities and the perceived urgency for increased national security is described and recommended. Contingent funding levels are provided to aid FEMA planning.

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ABSTRACT

This report summarizes the proceedings of the FEMA-sponsored conference on blast/fire-interaction research held May 18 through 21, 1980, at Asilomar, California. This conference, the third of an annual series, convened a selected group of authorities on fire effects, airblast effects, structural responses, and related technologies to reassess the significance of this nuclear-attack problem area and evaluate the contributions that ongoing studies are making, and proposed research could add, to alleviate the technical deficiencies which limit analytical progress. A continuing research program to upgrade the state of art at a rate consistent with national priorities and the perceived urgency for increased national security is described and recommended. Contingent funding levels are provided to aid FEMA planning.

SUMMARY

Fire from a nuclear weapons attack is a direct threat to the population of the United States and an indirect, long term threat to national survival, because fire can destroy the shelter, sustaining resources, and industrial machinery essential to economic recovery. Unresolved questions about interaction between blast effects and fire effects preclude any reliable estimate of the incendiary outcome of a nuclear attack on the United States. As such, these uncertainties are a major obstacle to defense planning and they interface with national security policymaking at the highest levels.

In an effort to rectify the technical deficiencies in predicting the incendiary outcome of a nuclear attack and to formulate a well-directed program of research, the Defense Civil Preparedness Agency contracted with SRI International in 1978 and again in 1979 to convene a conference of authorities on fire and blast, structural response, and related technologies. This report covers the proceedings of the third in the series of conferences, now under the sponsorship of the Federal Emergency Management Agency (FEMA) and describes the early activities of the DCPA/FEMA program of (nominal) 5-year duration, whose objective is to achieve an analytical method for reliably predicting fire behavior and incendiary outcome. Some substantive progress is reported.

Within a framework of crisis relocation planning, several questions need to be resolved, and several decisions need to be made promptly. A working concept of critical resources is paramount in realistic thinking about the fire problem and countermeasures to mitigate the threat. To avoid delay in strategic planning, this guidance should be developed, at least in preliminary form during the upcoming federal fiscal year (i.e., FY81).

A comparison of the recommended and actual funding to date shows that the program is getting under way at less than 60% of the original goal as urged in the 1978 conference. Accordingly, in assembling the revised FY80 program during the 1979 conference, a somewhat more austere program was acknowledged as a more realistic goal. While the austere plan continues to appear the most realistic to the 1980 conferees, in recognition of the always present possibility that national security funding might be increased, this year's program plans are presented in contingency format. As before, however, the focus is on the vulnerability of critical facilities and resources and the threats to survival of key individuals. This program, therefore, remains consistent with the broad objectives of the program as laid down in the first conference in 1978.

CONTENTS

ILLUSTRATIONS

TABLES

I INTRODUCTION

Background

In the event of a nuclear weapon attack, fire would be a direct threat to the population of the United States and an indirect, long-term threat to national survival, because fire can destroy the shelter, sustaining resources, and industrial machinery essential to economic recovery. Unresolved questions about interactions between blast effects and fire effects preclude any reliable estimates of the incendiary outcome of a nuclear attack on the United States. As such, these uncertainties are a major obstacle to defense planning and interfere with national-security policy-making at the highest levels.

To rectify the technical deficiencies underlying the lack of predictability of the incendiary outcome of nuclear attack on the United States and to formulate a well-directed program of research, the Defense Civil Preparedness Agency (DCPA) contracted with SRI International (SRI) in early 1978 to convene a conference of authorities on fire, air blast, structural response, and other related technologies. The report of the conference[1] identifies the technical deficiencies that prevent or inhibit the development of a theoretical or analytical basis for predicting fire effects under the uncertainties introduced by interaction with air blast waves and blast effects. It provides a logical, analytical framework for structuring and performing a research program to either eliminate technical deficiencies or reduce to an acceptable level the contribution these deficiencies add to the uncertainties in damage prediction. Recommendations are made for early attention to key issues that prevent the development of credible fire/blast models. Analytical modeling of blast-fire interactions is not only a goal of the program, but a necessary adjunct, through sensitivity analysis, of program planning and review.

A technical problem of this magnitude and complexity requires a program of at least 5 years' duration and involves a wide range of

interdisciplinary research activity conducted by government-agency laboratories and private research institutes, with appropriate assistance from industrial contractors. A program of such scope requires strong, consistently applied monitoring and coordination to (1) ensure that the obtainable goals are significant, (2) maintain a level of performance that is consistent with need, and (3) synchronize complementary or dependent elements. Toward this end, the 1978 Blast/Fire conferees urges DCPA to designate a lead laboratory to research key across-the-board elements of the program and to assist in coordinating the variety of tasks performed by contractors and other contributors. For a while SRI was able to fulfill some of the functions of a lead laboratory under contract to DCPA, but the concept was not formalized and failed to materialize completely.

Program implementation began in 1978, and a second conference was held in 1979.[2] In July 1979, by Executive Order of the President, the Federal Emergency Management Agency (FEMA) was created and emergency functions of the Government, including DCPA research activities, were transferred to FEMA's Director.

This document, the proceedings of the third conference, held in May 1980, includes an account of general session presentations, a brief review of the progress and status of current projects, the summaries and recommendations of the separate workshops, and it provides a projection of program activities and contingent levels of funding for the subsequent two fiscal years.

The keynote of this conference was the programmatical need for identifying critical facilities and key people. The keynote remarks are reproduced in full in Appendix A. Other supplementary background material is contained in Appendices B through E.

Agenda and Participants

The conference followed the now-familiar format developed over past years. Plenary sessions established the conference theme. Workshop

activities followed, interspersed with jointly attended, general-interest sessions. The conference concluded with a general session at which each Workshop reported on its activities and presented its recommendations for program research items and funding levels. The agenda is reproduced here along with a list of the participants for convenient reference.

REFERENCES

1. "Blast/Fire Interactions: Program Formulation," Final Report of SRI Project PYU 7432, DCPA Work Unit 2563D (October 1978).

2. "Blast/Fire Interactions: Asilomar Conference, March 1979," Proceedings of the Conference held at Asilomar, California, SRI Project PYU 7814, DCPA Work Unit 2563F (1979).

FEMA BLAST/FIRE CONFERENCE

ASILOMAR 1980, AGENDA

18 May, Sunday Evening - Introduction

1.	Welcome	D. Bensen, FEMA General Chairman
2.	Status of FEMA and the FY80 Program	D. Bensen
3.	Plans and Goals for the FY80 Conference . . .	J. Kerr, FEMA
4.	Collapse Strength of Floor over Basement . .	A. Longinow, IITRI
5.	Logistical and Procedural Matters . . . . . • Travel Arrangements • Reimbursement Procedure • Signup Lists for Workshops	S. Martin, SRI Conference Host

19 May, Monday Morning - Conference Keynote: Critical Facilities and Key People

1.	The Need to Identify the Critical Facilities and Key People	S. Martin
2.	Criteria for Determining the Critical Facilities and Key People . . . . • What and Who are they? • Where are they located?	R. Laurino, CPR Invited Speaker
3.	Formation of a List of Critical Facilities and Key People for this Conference	J. Kerr, FEMA
4.	Complete Workshop Assignments	S. Martin, SRI

19 May, Monday Afternoon - Blast/Fire Work Unit Reviews — J. Kerr, FEMA, Session Chairman

1.	Work Unit 2564E, Scale Modeling of Large Fires	R. Small, Pacific Sierra
2.	Work Unit 2563E, Blast/Fire Interaction Theory	F. Fendell, TRW
3.	Work Unit 2563F, Sensitivity Analysis and Technical Services	R. Alger, SRI
4.	Work Unit 2564A, Shocktube Experiments . . .	S. Martin, SRI

5. Work Unit 2564B, Thermal-Pulse Simulator . . J. Cockayne, SAI
6. LATA Ignition Experiments . . . . P. Hughes, LATA
7. Work Unit 2564C, Debris Distribution . . . . J. Rempel, SRI
8. Work Unit 2564D, Personnel Survivability . . N. Iwankiw, IITRI

19 May, Monday Evening - DNA Activities and Opportunities for Field Tests

1. FEMA Field Test Requirements (MILL RACE) . . R. Peterson, FEMA
2. DNA Studies of Secondary Effects . . . . . M. Drake , SAI

20 May, Tuesday Morning - Program Evaluation . . . . D. Bensen, Session Chairman

1. Critique of Program Relevance and Expediency — H. Brode, Pacific Sierra, Invited Speaker
2. Workshops Begin (Concurrent Sessions)

   - Workshop 1, Initial Fire Distribution After Blast . . . . A. M. Kanury, U. of Notre Dame
     - Debate Theoretical and Experimental Approaches and Interpretation of Results
     - Appraise Blast/Fire Experiments for Operation MILL RACE
     - Review FY81 and Formulate Workshop 1 Program for FY82
   - Workshop 2, Blast/Shock Effects on Structures . . . . C. Wiehle, DIA
     - Review Program Knowledge and Goals in View of Workshop 3 Requirements
     - Design Blast Structures Test for MILL RACE
     - Consider Key-People Shelter Criteria for Protection from Blast
     - Review FY81 and Formulate Workshop 2 Program for FY82
   - Workshop 3, Fire Growth and Threat to Critical FAcilities . . . . W. Parker, NBS/CFR
     - Review Information Required from Workshops 1 and 2 to Estimate Critical Facilities Losses and Inspire Countermeasures Concepts
     - Consider Key-People Shelter Criteria from Fire Standpoint

- Review FY81 and Formulate Workshop 3 Program for FY82 in View of No Starts to Date

- Workshop 4, Countermeasures to Protect Critical Facilities from Fire . . . . C. Wilton, SSI
  - Consider Key-People Shelter Criteria from Standpoint of Location, Size, Habitability, and Stay Time
  - Review FY81 and Formulate Workshop 4 Program for FY82 in View of No Support to Date

20 May, Tuesday Afternoon - Related Work and Other Matters — S. Martin, SRI Session Chairman

1. DNA Thermal Program . . . . J. Kennedy, DNA
2. Popcorn Soil Experiment with French Solar Source . . . . J. Cockayne, SAI
3. Greetings Extended by the Director, Office of Mitigation and Research . . . . . . R. Green, FEMA
4. Workshops Continue

20 May, Tuesday Evening - Open

21 May, Wednesday Morning - Program Reformulation, Redirection . . . . . . J. Kerr, Session Chairman

1. Brief General Session
2. Round Robin Interaction
   - Workshops 1 with 3, 2 with 4
   - Workshops 1 with 4, 2 with 3
   - Workshops 1 with 2, 3 with 4
     - Define Needed Information Exchanges
     - Clarify How Needs Fit Overall Requirements

21 May, Wednesday Afternoon - Workshops Continue

21 May, Wednesday Evening - "Show and Tell"

1. Views from Abroad . . . . V. Sjölin, Sweden
2. The Great Livonia Fire . . . . K. Kaplan
3. BRL Shocktube Work . . . . G. Coulter, BRL
4. Equipment Protection . . . . C. Wilton, SSI
5. Char Depth Experiments . . . . C. Butler, SRI
6. LATA Motion Pictures . . . . P. Hughes, LATA

22 May, Thursday Morning - Summary Reports

1. Reports by Workshop Chairmen
2. Windup, Conclusions . . . . D. Bensen/J. Kerr

22 May, Thursday Afternoon - Adjourn

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II PROGRAM OVERVIEW*

On behalf of the Federal Emergency Management Agency and SRI International it is my pleasure to welcome you to the Third Conference on Blast/Fire Interactions.

We have made considerable progress in the two years that have elapsed since the initial conference in May 1978. Many of the studies conceived by that conference are now coming to fruition. The results of studies that we will be discussing over the next several days will represent the first new information on the subject of blast/fire interactions that has been available in many years. I am looking forward, as I am sure you are, to these important proceedings.

I am sure you all have heard of the Federal Emergency Management Agency. However, in order to clarify some questions you may have about the objectives and responsibilities of FEMA and how civil defense is faring under the reorganization, I would like to briefly address these matters of interest.

Establishment of FEMA

The Federal Emergency Management Agency (FEMA) was established by Reorganization Plan No. 3 of 1978 and was made effective on April 1, 1979, by Executive Order. The Agency conducts functions under a number of Federal statutes which directly relate to federal, state, and local emergency preparedness and response. The basic principle of the Reorganization Plan is that federal authorities, in order to anticipate, prepare for, and respond to major civil emergencies, should be supervised and coordinated by one official responsible to the President. More specifically, the Director, Federal Emergency Management Agency, under Executive Order 12148 of July 20, 1979, establishes policies, for, and coordinates all civil emergency planning, management, mitigation and assistance functions of Executive agencies. The term "civil" emergency

*By D. Bensen, FEMA

is defined to include any accidental, natural, man-caused, or wartime emergency or threat which causes or may cause substantial injury or harm to the population or substantial damage to or loss of property.

FEMA, under the Reorganization Plan and subsequent Executive Orders, is responsible for performing functions that were, by law, assigned to the federal agencies from which FEMA was formed. These include: Defense Civil Preparedness Agency, Federal Preparedness Agency, Federal Insurance Agency, Federal Disaster Assistance Administration and U.S. Fire Administration. In performing these and other newly assigned functions it is the objective of FEMA to augment, reinforce, and extend existing efforts in crises emergency management, avoid duplication of programs that are provided currently by others, and initiate planning to fill unmet needs.

Civil Defense Under FEMA

The Defense Civil Preparedness Agency, under Public Law 81-920, "The Federal Civil Defense Act of 1950, as amended," brought to FEMA the responsibility "to provide a system of civil defense for the protection of life and property in the United States from attack."

For 1981, a $120 million civil defense program was requested. This represents a real increase of 12% over the FY80 appropriation of $100 million. The FY81 program would give priority to protecting people living near counterforce targets--SAC bomber bases, missile fields, and nuclear submarine ports. This would require priority effort in 31 states in areas that are especially vulnerable to a first strike in the event of a nuclear attack. The philosophy of this program is to focus limited resources in areas where they are most needed.

Amont the more significant changes proposed in the U.S. civil defense effort for counterforce areas are:

1. A 30% increase in survey efforts to locate shelter. This will include not only identification of fallout shelter areas, but the refined selection of the best available existing blast protection as well.

2. An additional 60 Nuclear Civil Protection (NCP) planners for the 31 states containing counterforce areas. They will complement the 155 NCP planners now engaged in community preparations to relocate Americans from 400 high-risk areas, should an escalating international crisis make evacuation necessary.

3. Another 11 planners to work in selected counterforce states to complete pilot plans to upgrade fallout shelters for evacuees in "host" areas--locations to which evacuees would be directed from risk areas.

4. An aggressive sign identification program in counterforce areas for about 4,000 buildings that will offer protection against nuclear attack. Selected shelters in these areas will also be stocked with water containers, sanitation kits, and manually operated ventilation devices.

5. Assignment of a radiological defense officer to each of the 31 counterforce states to plan for and train monitoring personnel. They will work to improve monitoring capabilities for detecting and reporting radiation levels in either a wartime or peacetime nuclear crisis.

Additional stepped up civil defense activities in counterforce areas will include austere emergency operating centers, their associated communications links, and a 50% increase in training for key decision-making officials and managers for shelters.

Planning will also begin for an accelerated civil defense buildup ov-r . period of about a year, because of markedly increased international tensions.

Another expanded FEMA effort will go into plans to maintain continuity of governments in case of emergency, in peace or war. Such planning provides for orderly succession to office, redelegation of emergency authority, safekeeping of essential records, emergency and alternate relocation sites and communications, and protection of government resources, facilities, and personnel.

The Office of National Security in the Mitigation and Research (M&R) Directorate of FEMA is responsible for providing the research necessary

to develop the technical basis for FEMA's program in civil defense. The program should provide maximum in-place protection for the population against a short-warning nuclear attack or during a severe crisis, in the event that the decision is made not to relocate. It must also cover the protection of populations relocated from areas where there is high risk from the direct effects of nuclear weapons or those endangered by hazards accompanying a nuclear incident in peace-time. It must cover credible protection for key personnel who must remain in high-risk areas during a crisis and, to enhance recovery from an attack, the program should have provisions to reduce the vulnerability of industry. The aim of FEMA's research program is to provide both short- and long-term support to these goals.

Research within the Office of National Security is conducted within five broad areas:

- National security studies
- Weapon effects
- Nuclear hazards
- Population protection measures
- Industrial protection measures.

Status of Blast/Fire Research

Fire at Hiroshima and Nagasaki was one of the principal devastating effects of the explosions. However, because of the uncertainty and unpredictability of nuclear-weapon fire initiation and spread, the effects of fire have since been either ignored or given only perfunctory treatment in most damage assessment studies and in civil preparedness planning.

As stated in the summary of Workshop 1: "Initial Fire Distribution After Blast Effects," published in last year's Conference Proceedings, what is not known from wartime experience is:

- How many fires were ignited by thermal radiation?
- How many fires were blown out by blast?
- How much transporting of fire brands took place?

- How many secondary (blast disruption) fires occurred?

Although these questions referred specifically to what is not known about the nuclear explosions in Hiroshima and Nagasaki, they continue to be the principal issues of uncertainty about the outcome of possible future events, issues that we need to address at this conference.

Funds allocated in support of blast/fire research were $530,000 in FY79 and are about $725,000 in FY80. They make up over 25% of the total budget for civil defense studies. Table 1 shows the projects that were funded in FY80.

Table I-1

FUNDED FY 1980 BLAST/FIRE PROJECTS (Work Unit Nos.)
(Total $725,000)

Blast/Fire Casualty Estimation (2564D)
Debris Distribution (2564C)
Predictive Fire Modeling (2564E)
Sensitivity Analysis/Program Review (2563F)
Secondary Fire Analysis (*)
Shocktube Blowout Experiments (2564A)
Theory of Blast/Fire Interaction (2563E)
Blast/Fire Response Mechanisms (*)
Thermal Source Development (2564B)

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*Not procured at time of conference

Table I-2 lists the projects recommended by last year's conferees for which funds were unavailable:

Table I-2

RECOMMENDED BUT UNFUNDED PROJECTS

	Amount (thousands)
Blast Analysis of Urban Complex	$ 160
Verification Field Experiments	50
Fire Vulnerability of Critical Resources	250
Utilization of Five-City Study Results	50
Target-Specific Model of Critical Resources	80
Define Essential Industry and Key Workers	30
Site Selection for Key-Worker Shelter	40
DASIAC Film File Check (B/F)	30
Total	$ 690

From this list it is apparent that a number of important studies were not undertaken in FY80. Hopefully additional funds will be made available next year so that we may expand the effort and continue the program as outlined by this group.

Opportunities for verification by field experiments, other than thermal tests, were not available in FY80. Two large-scale ignition experiments were conducted for us through the Defense Nuclear Agnecy by Los Alamos Technical Associates, Inc., under the direction of Peter Hughes and in consultation with Stanley Martin and Ray Alger of SRI International. The results of these experiments will be presented during the Monday afternoon research briefing session.

The definition of key industries and identification of key workers, while recognized as crucial to crisis relocation planning and to the establishment of blast/fire protection criteria, were not considered under this program. Some work on these problems is being funded by the operations side of FEMA and will be reported on tomorrow morning by Richard Laurino of the Center for Planning and Research.

The recommended FY81 blast/fire program developed at last year's conference is as follows:

Table I-3

PROPOSED FY 1981 BLAST/FIRE PROGRAM

	Amount (thousands)
Shocktube Studies of Blowout	$ 100
Field Tests	
Blowout	200
Structural Response	400
Mixed Fuel	80
Theory of Shock/Fire Interaction	100
Analysis of Individual Structures	100
Complementary Blast Studies	100
General Model of Fire Spread and Threat	200
Application of Computer Simulation and Decision Analysis to B/F Countermeasures	100
Program Review/Conference	60
Recommended budget	$1,440

A significant part of the recommended FY81 budget is for field tests in conjunction with the Defense Nuclear Agency's MILL RACE event, a 600-ton ANFO high explosive test planned for execution in September or October 1981. In addition to the opportunity to test a number of blast shelter concepts, a Thermal Radiation Effects Simulator (TRES) will be available to permit some benchmark tests on blast/fire interactions. We will hear more about the test and test opportunities from Tom Kennedy, DNA, later in the program.

FEMA was invited by DNA to participate in MILL RACE. Captain Peterson, FEMA/M&R, will present a number of proposals that we, in consultation with SRI International and Scientific Service, Inc. have submitted to DNA. The estimated cost associated with the proposed tests is much higher

than our projected budget will permit, so we will be asking you to help us establish priorities or scale down the work to obtain the maximum amount of information within the available funds. There is also a possibility of cooperating in the experiments of others. This approach should be explored.

The estimated cost to fund all of our proposed field tests is $1.6 to $2 million. It is obvious that a great deal of paring is needed to arrive at an affordable program.

The Office of Mitigation and Research is responsible for all aspects of R&D relating to any topics relevant to the FEMA mission. Thus, the foregoing account of the National Security program describes efforts that mesh with other fire work. Most notable among these are: the fire-service and life-safety oriented studies conducted by the U.S. Fire Administration; the basic science program of National Bureau of Standards, using USFA funds; and the management-oriented studies run by other pieces of M&R under James W. Kerr's supervision. These programs impact most heavily on Workshop 4 (Countermeasures) and as reflected in their deliberations, reported later in Chapter VI.

III KEYNOTE MATERIAL

In recent years we have attempted to focus attention on the impact that blast/fire effects would have on industrial capability and economic viability. Such efforts often seem frustrated by a lack of clear definition of which industries, facilities, and utilities are, in fact, critical and which of the personnel associated with these are really essential to sustaining their output (i.e., lack of an official designation of "critical facilities" and "key workers").

Accordingly, at this year's conference we sought to stimulate discussion of these issues in the hope that this could either (1) resolve the question for purposes of B/F research planning, or (2) lead to a recommendation that (post-conference) attention be directed to meeting this requirement. We implemented this plan as follows: (1) The subject of "Critical Facilities and Key Workers" was formally introduced as a keynote of the conference; (2) Dr. Richard Laurino (Center for Planning and Research) was invited to deliver an informational, state-of-the-subject presentation of the keynote topic; and (3) the conferees were encouraged to present their views. Dr. Laurino's remarks are reproduced in Appendix A. The following is only a brief synopsis of the presentation and the discussion that followed.

Dr. Laurino pointed out that at present, no definitive guidance exits, although some spotty efforts are being given to the problem. There are obstacles to any attempt to generate a list, and it may be quite unrealistic to contemplate any one list to cover all issues. Agreement must first be reached on national objectives, and even then the definition of <u>essential</u> varies from one scenario to another, one phase of the emergency to another, and it differs very much, depending on <u>agency point of view</u>. All major alternatives need to be considered.

Following Dr. Laurino's presentation, the conferees expressed their own thoughts and suggestions. At least three unrelated lists of critical

facilities and key people can be envisioned, depending on the selecting agency and its requirements.

- Department of Commerce
- Department of Defense
- FEMA [Crisis Relocation Planning (CRP)]

The list to meet CRP requirements would be substantially shorter than the list to maintain commerce and the economy. Various factors precluded formation of a specific list; consequently, the discussion concluded with some general guidance about the number of people that might be sheltered, and some criteria for the shelter. The level of mobilization and national goals would have a strong impact on decisions about critical facilities and people, and could be diametrically opposite to CRP efforts to minimize the number of people at risk. Current thinking about CRP is that about 80% of the people in a risk area would be evacuated, 15% would refuse to move, and about 6% would fall into the key-worker category. It was tentatively concluded that

- About 3 to 8% of the population would be classified as key workers.
- These workers should be provided with shelter hardened to at least 15 psi.*

Most of the discussion centered on shelters for key workers, and questions about the great variability in blast/fire vulnerability expected from industry to industry remained untouched.

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*Editor's note: But also see further discussion of key-worker shelter requirements in the Workshop 2 summary of Chapter VI.

IV REVIEW OF CURRENT PROJECTS

This chapter reproduces the summaries provided prior to the conference by contractors responsible for the currently active Work Units.

FEMA Work Unit No: 2563F

Work Unit Title: Sensitivity Analysis of Blast/Fire Predictions and Services to Assess and Document Status of Technical Knowledge

Objective and Scope:

1. Determine the relative importance of the various input parameters for predicting blast/fire interactions. Perform a sensitivity analysis to determine the effects of assumptions about (1) the debris description, (2) primary ignitions and (3) secondary fire starts on the blast fire damage estimates.

2. Summarize the status of fire-development, spread, and damage models with particular emphasis on the consequences of the implicit and explicit assumptions incorporated in the models.

3. Assess and document the status of technical knowledge on nuclear weapon detonation-induced blast/fire interactions.

4. Evaluate suitability of field test opportunities for advancing the state of the art of predicting blast/fire effects. Assist FEMA in planning for agency-sponsored participation as appropriate.

Contractor: SRI International
333 Ravenswood Ave.
Menlo Park, CA 94025
(415) 326-6200 (Extension 3578)

Contractor Personnel: Stanley B. Martin, Raymond S. Alger and John R. Rempel*

*Center for Planning and Research

Approach

Task 1. Blast/Fire Interactions

The research plan incorporates two complementary approaches. One exercises the existing SRI Blast/Fire model to determine the sensitivity of the initial fire distribution to the influence of the key variables and simplifying assumptions. The other examines fire intensity-time conditions necessary to threaten shelterees and irreparably damage machinery protected against blast effects to establish how well (i.e., how confidently and in what detail) the fire consequences must be forecast.

A. Basic Approach--Initial Fire Distribution

Chronologically, this analysis commences with the nuclear detonation and follows events until the number of primary and secondary fires has been established in essentially undamaged structures. This task entails the following four steps:

Step 1--Review the 1970 Dikewood Analysis of the Models used in the Five-City Study to identify: (1) the key variables and their plausible value ranges as perceived by the authors of that previous study, and (2) the differences between modeling approaches that they determined to be responsible for the major differences in prediction results.

Step 2--Use the most recent applicable version of the SRI Blast/Fire Model to estimate initial-fire frequency functions (i.e., probabilities of fire starts as functions of distance from G.Z.) for:

- Two or more weapon sizes in the strategic-yield range
- A surface-burst and a low air burst.
- Two or more land-use categories including areas representative of residential and industrial (manufacturing) occupancies.
- Several atmospheric conditions covering the practical range of thermal transmission factors.

and test the sensitivity of the results to: (1) the basic assumptions used in developing the model, (2) the algorithms invented to cover the lack of factual data, and (3) the variability (natural dispersion) in weather conditions,

target changes resulting from population response to warning, and other scenario-related variables.

Step 3--Compare the inherent uncertainties due to scenario variables with the potentially correctable uncertainties due to technical deficiencies. This will guide the establishment of practical goals for predictive modeling and the associated requirements for resolutions of technical uncertainties.

Step 4--Rank the factors, contributing significantly to uncertain predictions, according to sensitivity and amenability to resolution through research. This will be expressed in matrix form for ready guidance to decisions about assignment of priorities for research attention, in allowing for scheduling in logical sequence, and for making cost-effective tradeoffs in choice of alternative funding programs.

B. Supplemental Approach--Blast Effects Modeling Requirements

Since existing fire models do not deal with sustained fires and fire spread in severely blast damaged regions of an urban target, they provide no evidence regarding the dependence of fire development on structural collapse and makeup of the resultant debris field. Therefore, this second approach examines the requirements for modeling of blast effects and debris-field descriptions in the context of fire intensities and durations that clearly threaten people in sheltered locations and industrial machinery and equipment expediently protected from (or unprotected, but chancing to survive) blast damage. Attention is focused on the question of how the fire's intensity and duration vary with fuel characteristics whose changes are identifiable with blast effects on target elements. This supplemental approach entails the following three steps:

Step 1--Estimate the critical fire intensity levels required to destroy major machinery on the basis of historical records, particularly war-damage records. Part of this task will entail identifying critical* types of equipment and seeking statistical data on structures housing these.

Step 2--Estimate effects of structural damage on the fire time-intensity levels both for spreading fires and fires

*i.e., critical to war fighting and post-war recovery.

where all the structures ignite simultaneously. These estimates will involve tenuous extrapolations from meager data and expert opinions.

Step 3--Estimate significant differences in the damage levels required for descriptions of (1) extent of structural collapse and (2) the debris field.

Task 2. Status of Fire-Development, Spread, and Damage Models

Prepare a paper for the FY79 planning conference outlining the strengths, weaknesses, and factors that must be resolved if such models are to satisfy the needs of the overall blast/fire program.

Task 3. Program Review Conference (Asilomar 1979)

Plan, organize, and host a technical conference on blast/fire interaction and prepare documentation in the form of conference proceedings, and analysis of the findings and priorities for future research needs relevant to the problem of blast/fire interactions.

Task 4. Advanced Planning for Large-Scale Test Program

Maintain surveillance of test opportunities pertinent to the FEMA Blast/Fire Program; e.g., the Misty Castle Series, Burbank, Lark, etc. Provide guidance in planning and execution of such large-scale experiments.

Status

The major thrust of the FY79 program dealt with the March Asilomar Conference on Blast/Fire Interactions; i.e., task 3. Both tasks 1 and 2 were discussed at the Conference and the paper on fire development and damage models (task 2) was included as appendix E in the Conference Proceedings. A paper covering the Supplemental Approach i.e., task 1B has been completed and will be published when the companion effort (Task 1A) is finished. The principal FY79 activity in task 4 involved ignition measurements with the DNA Thermal Radiation Simulator at Kirtland AFB. This effort was cooperative with the Los Alamos Technical Associates, Inc. who conducted the field tests. Our participation involved assistance in designing the tests and interpreting the results. All tasks are essentially on schedule. The formal report of the sensitivity study is in preparation.

Significant Results

Task 1A

Table IV-1 lists the variables incorporated in the SRI model, divided into three categories of uncertainties. The inherent uncertainties involve those source and radiation transport parameters that are beyond our control, and no amount of effort will reduce these uncertainties appreciably. In the Five City Study and in the current exercise, specific values were arbitrarily assigned as indicated in Table IV-1 to provide a range of reasonable values.

The second group of uncertainties involves the target description. In principle, these parameters can be described with any desired degree of accuracy; however, in practice, the cost and effort preclude precision in the microstructure description. These fine fuels and their view-factors of the source are in a constant state of flux; consequently, class-average values have been assigned to these target parameters, e.g., residential versus industrial, windows covered versus windows uncovered, flat land versus mountainous, and three wall-to-window area ratios, i.e., 0.1, 0.2, and 0.5.

The third group of uncertainties involves the physics and chemistry of the problem that go beyond our present state of knowledge. In the SRI model, various algorithms are introduced to bridge these deficiencies, and the validity of the assumptions ranges from fair, where there is some experimental justification, to poor, when based on a dignified guess. Additional knowledge should materially reduce the uncertainties in the descriptions of the mechanisms, and indeed the lion's share of the current FEMA program is devoted to improving estimates of fires that survive the effects of airblast.

Inherent uncertainties due mainly to the unpredictability of an attack scenario dominate the question of sensitivity and, in fact, compel the choice of a predictive model. Technical deficiencies (the potentially correctible uncertainties) are totally outweighed by the effects of plausible scenario variation. This raises again the question

Table IV-1

SENSITIVITY ANALYSIS

Variables	Current Study Values
Attack	
Weapon yield (type)	5 MT (±0)
Thermal partition	1/3 (±0)
Ground zero location	Unspecified
Height of burst	Surface and 500 scaled ft (±0)
Time of day, year, etc	Unspecified
Target	
Land use and occupancy	Residential, commercial industrial (per 5-City Study)
Construction type/density	Per San Jose in 5-City Study
Distribution of ignitables	Per San Jose in 5-City Study
Weather (present and recent past)	Per San Jose in 5-City Study
Atmospheric transmission	Per Magdeburg annual statistics (Drake)
State of warning/preparedness	Minimal, windows covered/ uncovered
Previous damage	None
Response	
Ignition thresholds	Correlation per NRDL
Airblast extinction thresholds	Algorithms per Goodale
Structural damage	Minimal or none
Fuel redistribtuion	None
Fire growth/spread	Not treated
Extent of fire damage	Algorithms per Colvin

of the relevance of weapon-effects modeling of whole urban areas as predictive tools in civil defense planning and preparedness exercises. These questions of relevance will be discussed at the conference.

Task 1B

This supplemental approach focused on one category of critical facilities, namely, machine tools and the potential for surviving the blast and fire threats from a nuclear attack. Considerable information is available about number, types, geographical location, and industrial application of essential machine tools; however, virtually no records exist of the structures wherein these machines are housed. World War II experience in Japan and Germany, plus the results of nuclear tests have established the importance of the structures to machine tool survival; few machines were lost to blast alone and substantial loadings of combustible materials were required to inflict serious fire damage. For example, 74% of the Nagasaki machine tools in the blast- and fire-damaged area survived the nuclear attack with only minor damage. In Hiroshima the losses were slightly higher because of the flammable buildings but even in the wood-frame buildings, only about 41% suffered serious damage. Under conventional bombing attacks with high explosive and incendiary bombs, the German machine tool industry suffered only about a 10 to 15% loss, mostly due to fire in combustible surroundings. Even in one of the greatest peace time fires (i.e., the General Motors' Livonia Fire, which burned a 34.5 acre plant in 12 hours), 73% of the 3,310 machines were salvaged. History provides an optimistic picture of the survival potential for critical machine tools, provided they are housed where the fire potential is modest. To estimate the potential for losses in the United States, we need information about the distribution of machines in the various classes of structures and the overpressures where combustible roofs will collapse and burn around the machines. Table E-1 in the 1979 Conference Proceedings summarizes the types of structures where fire is a threat to resident machine tools and where roof collapse information is needed to evaluate the fire threat.

Task 2

The survey of fire development, spread, and damage models raised several questions that require answers before the blast/fire program can progress very far.

- What are the critical facilities and who are the key people in the context of a crisis relocation plan for civil defense and post attack recovery? This information is essential to bound the problem of evaluating losses and developing mitigation countermeasures.
- Considering the state of fire spread models and the problems discussed under task 1A, which of the alternate methods of approach are most promising and realistic within the available time and support constraints (i.e., city wide fire spread modeling or fire vulnerability assessment of the few critical facilities and shelters)?
- How important are ignition field and debris field details in both approaches?

Task 4

The results of the field test ignition experiments will be discussed by Peter Hughes of LATA and Pres Butler, SRI. Planning for Operation MILL RACE will be presented by R. Peterson (FEMA).

Reports: Blast/Fire Interactions, Proceedings of Asilomar Conference, March 1979, edited by R. S. Alger and S. B. Martin, SRI Project PYU 7814.

SUMMARY

FEMA Work Unit No: 2564A

Work Unit Title: Shocktube Experiments on Extinction of Fire by Airblast

Objective and Scope: The overall objective of this project is to determine and evaluate the physical variables that govern extinction of sustained burning, in representative urban fuels, caused by exposure to simulations of airblast from nuclear explosions. The first year's effort, just concluded and reported, was limited to targets of flat-plate geometry in edge-on position to the incident shock, and was mainly focused on displacement as a mechanism for extinguishment.

Contractor: SRI International
333 Ravenswood Ave.
Menlo Park, CA 94025
(415) 326-6200 (Extension 3578)

Contractor Personnel: Stanley B. Martin, Raymond S. Alger, Thomas C. Goodale, and Robert G. McKee, Jr.

Approach

Flame blowout tests were run in the SRI-developed shocktube facility, which is specifically designed for investigating the interactions of blast with fire by direct observation of the phenomena and dependence of these phenomena on the basic characteristics of nuclear air-blast waves. The facility provides repeatability of test conditions and convenience of operation, and allows many tests to be conducted in a relatively short experimental program at reasonable cost. Systematic investigation is possible through independent variability of air-blast characteristics over the practical range of values for civil defense concerns.

This facility has been used during 1979 for experiments in air-blast blowout, mostly of Class-B (i.e., hexane-fueled) fires. Only a modest

experimental effort was possible because modification of the facility to accommodate these experiments absorbed a substantial part of the available funds.

Status This project is substantially on schedule as planned. A work plan for continuation has been submitted to, and approved by, the cognizant FEMA technical officer.

Significant Results The limited data resulting from the FY79 effort, as yet unstructured by a theoretical model, allow us to offer only tentative conclusions. Within limitations of the test facility and conditions imposed, the following conclusions seem justified for the flat-plate geometry, zero angle of attack attitude, and for volatile Class-B fuels stabilized mechanically by inert substrates:

- Flame displacement is a mechanism of extinguishment.
- Extinction threshold conditions scale with fuel bed length; more specifically, for 70 to 300 ms pressure pulse durations, the critical bed length is approximately proportional to peak overpressure (in the range of 1 to 5 or more psi) and appears proportional to particle displacement during the positive phase. The critical length is, however, only about 1/6 of the particle displacement for the waveform used.
- Results do not seem to depend upon the texture of the substrate.
- The effect of a barrier is pronounced and apparently very sensitive to location. Even a small perturbation introduced into the flow immediately in front of the fire may allow it to survive air-blast conditions that would otherwise readily blow the fire out. However, this "stabilizing wake" does not persist to appreciable downstream distances (less than, say, ten barrier heights).

The single datum on a Class-A fuel is totally inadequate to permit comparisons with Class-B fuels. However, the displacement mechanism seems to apply also to extinction of flames over Class-A fuels in flat-plate configurations oriented edge-on to the incident shock.

Recent exploratory tests with more complex targets, including wood cribs, indicate that fires may survive peak overpressures of 10 psi and

<u>Reports</u>: Stanley B. Martin, "Experiments on Extinction of Fires by Airblast--Flame Displacement as an Extinction Mechanism," Annual Report, FEMA Work Unit 2564A, SRI International, Menlo Park, CA (January 1980).

SUMMARY

FEMA Work Unit No: 2564B

FEMA Work Unit Title: Developing a Thermal Flux Simulator

Objective and Scope: Do a literature search on radiant sources, develop a bench model of a thermal pulse irradiator for ignition of common materials with a 1 MT or larger yield waveform, and assemble a full-scale system in the FEMA facility at Camp Parks, California.

Contractor: Science Applications, Incorporated
8400 Westpark Drive
McLean, Virginia 22102
(703) 821-4300

Contractor Personnel: Dr. John E. Cockayne

Approach: After establishing the low flux requirements, a carbon blackbody was selected for development.

Status: The bench model was recently completed behind schedule due to repeated carbon-rod holder burnouts at 1500 amperes. The FY80 effort will commence shortly to merge with an SRI International effort in early FY81 (late CY80) for installation and checkout at Camp Parks before Christmas.

Significant Results: The SAI carbon-rod radiant source (SAICARRS) has been operated in an unshuttered mode to simulate the thermal flux waveform from a 1 MT nuclear burst for a 100 J/cm^2 (24 cal/cm^2) fluence. The flux pulse was obtained by rapidly resistively heating the carbon rod to near melting temperature (>3500°C) and then cutting off the electrical power to permit a natural blackbody radiative decay of temperature and radiance. Although the color temperature is biased toward the near-infrared, this system will only cost ten percent (10%) of an equal fluence flashlamp capability that has a better blackbody temperature approximation during the pulse. The SAICARRS has a large growth potential with respect to simulating sub-megaton yields, which can already be simulated by the special shock tube operated by SRI. Another future SAICARRS option is flux variation at constant color temperature below 4000K.

SUMMARY

FEMA Work Unit No.: 2563E

FEMA Work Unit Title: Modeling of Fire/Blast Interactions -- Aspects of Fire Spread

Objective and Scope: To develop a generalized approach toward establishing approximate criteria for the extinction of burning (of an object outgassing combustible vapor), upon the onset of a forced-convective flow. Such a flow is associated with the arrival, at a site of a radiation-precursor-initiated fire, of the shocked gas behind the blast wave. The scope is limited in this work unit to quasisteady modeling of the phenomena.

Contractor: TRW Defense and Space Systems Group
One Space Park
Redondo Beach, California 90278
(213)536-1624

Contractor Personnel: Francis Fendell (principal investigator)
Phillip Feldman (member of the technical staff)
George Carrier (consultant)

Approach: Subsonic isobaric forced-convective flow of air past a pyrolyzing body outgassing combustible fuel vapor is examined according to standard aerothermochemical (Shvab-Zeldovich) formulation. The phenomenon is related to the counterflow-diffusion-flame two-point-boundary-value problem for describing extinction of burning stabilized on any simple bluff body. Thus, known results for the minimum Damköhler number (ratio of forced-convective-flow residence time to chemical-reaction time) compatible with vigorous burning of large-activation-energy, large-heat-of-combustion, counterflow diffusion flames are applicable.

Status: Project completed and final report issued in October 1979.

Significant Results: With knowledge of the kinematic field for flow about a body, and with a suitable global model for the chemical kinetics, one can obtain the criterion for diffusion-flame extinction, by (1) obtaining the relatively facile solution for certain passive scalars, and, then, (2) utilizing known results for a counterflow diffusion flame. Thus, for prescribed post-shock flow conditions, the means of ascertaining whether the flow speed is adequate to blow out the diffusion flame enveloping a sublimating

body ignited by the radiative precursor is now set forth in a rather general approach. Results indicate that some forced-convective extinction is highly likely, according to the following scenario. Downwind displacement of both hot burned vapor and cold unburned vapor, previously pyrolyzed from combustible matter, is the mechanism by which the arriving shocked gas disrupts the pre-existing fire. The large thermal inertia of the solid phase relative to the gaseous phase permits pyrolysis to resume after passage of the blast. The homogeneous diffusion flame can be reestablished, if the shocked air is not flowing too quickly, relative to the rate of the controlling chemical-kinetic step of the gas-phase combustion. However, mastery of a quasisteady formulation of this competition, for an isolated subliming body, is only a first step in a sequence of investigations which are needed to understand post-nuclear fire scenarios. Other immediate questions that balance importance and tractability concern (1) how the above extinction criteria are changed when the wind has a sudden onset and is followed by a "steady" diminution; (2) how does the mutual radiative enhancement from a configuration of two or more closely spaced burning objects alter the results; and (3) what are the effects of char on flame-extinction criteria, since in fact most solids do not gasify via sublimation.

Reports: George Carrier, Francis Fendell and Phillip Feldman: "Forced-Convection Extinction of the Diffusion Flame Supported by a Pyrolyzing Body," TRW Report 34488-6001-RU-00, October 1979, 26 pp. plus figures (accepted for presentation at the 15th International Congress of Theoretical and Applied Mechanics, Toronto, Canada, 17-23 August 1980.)

SUMMARY

FEMA Work Unit No: 2564C

FEMA Work Unit Title: "Debris Distribution as a Parameter in Blast/ Fire Interaction"

Objective and Scope:

The objective of the research is to determine those debris distribution features that are important to fire initiation and spread. The scope of this phase is to begin the definition of the environment in which the blast/fire interaction occurs by calculating various likely distributions of wall debris imposed by the nature of the structure and of the blast wave.

Contractor: SRI International
Menlo Park, Ca 94025
415-326-6200

Contractor Personnel: (Principal investigators) John R. Rempel

Approach

Calibrate wall collapse prediction methods and debris translation models against existing field observations (e.g., Prairie Flat and Dial Pack); enhance an existing computer program to treat a single story of a large U.S. building (e.g., hospital, office building); then apply these techniques to an example building at two overpressures: one near incipient collapse and a second near 30 psi.

Status

Calibration phase is complete. Description of the collapse of a major

building at two overpressures near incipient collapse and in the high pressure region (30 psi) is nearing completion.

Significant Results

By adjustment of aerodynamic drag and lift coefficients and ground sliding friction coefficients, rough correlation with observation of debris translation at Dial Pack and Prairie Flat has been achieved, and final house debris patterns at Prairie Flat can be simulated at 30 psi. Patterns at 9 psi are ambiguous at present and probably cannot be resolved without motion picture information. Substantial improvements to an existing computer code have been made so that walls and floors located in one story of a large building may be analyzed in one computer pass taking into account certain interactions. The resulting code has been used to make a preliminary analysis of Landis Hospital (Philadelphia).

Reports: none

SUMMARY

FEMA Work Unit No.: 2564D

FEMA Work Unit Title: Assessment of Combined Effects of Blast and Fire on Personnel Survivability

Objective and Scope: Develop an analytical procedure to realistically assess the combined effects of blast and fire on personnel survivability

Contractor: IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616
(312) 567-4799

Contractor Personnel: A. Longinow and N. R. Iwankiw

Approach: Groupings of urban buildings will be defined. These will include single family and multi-family residential units. Selected buildings will be grouped in an area approximately the size of one city block. Each different building type (4 basic types assumed) will be analyzed to determine its incipient collapse blast overpressure. Probable failure modes and debris patterns, sizes and properties will thereby be postulated. After debris distributions are computed, the debris fire behavior, i.e., rate of spread, intensity and duration, will be estimated. Personnel survivability will then be assessed from both blast and fire effects.

Status: A probabilistic debris transport model has been developed. The types and groupings of buildings have been identified. Incipient collapse overpressures have been computed for each building type and debris catalogues are completed. The debris distribution analysis is now in progress.

Significant Results: A general two-dimensional probabilistic debris transport computer model has been developed and exercised. Building failures modes have been analytically evaluated and the related debris properties have been estimated.

SUMMARY

FEMA Work Unit No: 2564E

FEMA Work Unit Title: Physics of Large Urban Fires

Objective and Scope: Examine the state of understanding of large scale urban fires and thorough review and analysis recommend candidate studies for future research efforts.

Contractor: Pacific-Sierra Research Corporation
1456 Cloverfield Boulevard
Santa Monica, California 90404
(213) 828-7461

Contractor Personnel: Dr. H. L. Brode, Dr. R. D. Small

Status: Approved Final Report in press

Approach and Significant Results: Large scale urban fires which may accompany natural disasters or result from war-time actions were explored. The literature pertaining to the macroscopic physics of large area fires was reviewed and analyzed, and areas where current understandings are deficient were identified. Features specific to a nuclear-weapon-initiated city fire were considered in detail. Based on hydrodynamic and thermodynamic principles, a self-consistent physical model was constructed which accounts for the unique properties of large-area fires. Because of the scale of such events, a significant perturbation to the atmosphere results, and a recirculation flow field is established. This accounts for the high velocity winds characteristic of firestorms observed in WW II fire bombings. Development of the governing equations shows that the urban area interactions are principally inviscid. Scaling suitable for formulation of small scale experiments was derived based on a component model. Recommendations for future experimental and theoretical modeling studies are made in areas that would aid in emergency management of large scale fires and in dealing with disasters in which uncontrolled fire may play an important role (e.g., earthquakes, nuclear warfare, revolution).

Reports: PSR Report 1010, March 1980

V RELATED WORK

The Defense Nuclear Agency and FEMA have a common interest in the blast/fire effects of nuclear weapons, although the responsibilities of the two agencies are distinct. DNA has recently been reviewing its potential role in this area of combined nuclear weapons effects and is beginning to plan and implement a program that is pertinent to DNA's needs. The thermal radiation source (TRS) development and its planned use in the upcoming MILL RACE field event is, in part, a response to this requirement. As of this date, however, only FEMA has plans for blast/fire experiments at MILL RACE. Nevertheless, the complementary aspects of the two programs bode well for interagency cooperation. This chapter reproduces three reports on work related to fires and the thermal program.

EVALUATION OF SECONDARY WEAPON EFFECTS*

The objective of this research program is to investigate the contribution that secondary weapon effects, such as fires, destruction of life support systems, etc., may make to casualties and other forms of damage caused by the use of nuclear weapons against targets in built-up areas.

Current casualty estimation procedures are based primarily on "primary" weapon effects. These include initial nuclear radiation, fallout nuclear radiation, airblast and thermal radiations. There are a number of secondary effects that have the potential of causing casualties. The following is a list of some secondary effects.

- Fires (burns, toxic gases, smoke)
- Damage to health-care systems (non-lethal to lethal injuries)
- Damage to residences and other shelters (exposure)
- Damage to sanitation systems (disease and infections)
- Damage to damage control systems (fire-fighting, rescue, etc.)

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*Marvin K. Drake, SAI

- Damage to food supply systems
- Damage to water supply systems
- Damage to utility systems
- Damage to transportation systems.

The approach being used for this program is to (1) synthesize the results from previous weapon effects research relevant to secondary weapon effects and the relationship of these effects to casualty-producing mechanisms in order to determine whether or not there is sufficient information available to make realistic secondary casualty predictions; (2) review and analyze the results of previous wartime and natural disaster experiences with respect to similar effects; (3) integrate the results from the weapon effects research (microscopic analysis) and previous experience (macroscopic analysis) to develop a prediction capability; (4) perform analysis for some example scenarios to identify when secondary effects are important and how important they might be; and (5) make an assessment of the uncertainties of secondary weapon effects predictions for the various scenarios.

The results of this research should determine whether or not secondary weapon effects are important and establish the basis for developing a methodology for use in predicting secondary weapon effects.

FEMA Field Test Requirements, MILL RACE*

Table V-1 is a listing of proposed field test experiments which were submitted recently by FEMA for possible inclusion in the Defense Nuclear Agency MILL RACE, 600-ton field test, now scheduled for August-October 1981. The listing was submitted to DNA with the stipulation that it was our intention to review our testing requirements during the Asilomar conference and to submit revised experiments following that review. Accordingly, the experiments were described to the Blast/Fire Conference participants during the session on DNA Activities and Opportunities for Field Tests, and were discussed at that time. Subsequently, Workshop 1 appraised

*By Richard Peterson, FEMA

Table V-1

PROPOSED FEMA EXPERIMENTS FOR DNA OPERATION MILL RACE

Originator	Experiment	Originator's Priority	Blast (psi)	Thermal (cal/cm^2)	Preliminary Cost Estimate ($)*
FEMA	Key-Worker Expedient Shelter Test	1	35 & 50	-	20,000
FEMA	Upgraded Host Shelter	2	1.5	-	40,000
FEMA	Structural Blast/Fire Test	3	2-5	10-25	40,000
FEMA	Thermal Flash Test (Specimens)	4	2-5	25,20,15 & 10	5,000
SSI	Host Area Shelter	1	2	-	132,000
SSI	Industrial Hardening - 20 psi	2	20	-	80,000
SSI	Key-Worker Shelter Test	3	40	-	264,000
SSI	Industrial Hardening - 40 psi	4	40	-	106,000
SRI	Responses of Structures and Debris Translation	1	3,4,6 & 12	-	454,000
SRI	Airblast Extinction of Fires Structures	2 1	3,6,7.3, & 8	10-20+	314,000
WES	Blast Upgrading of Existing Structures	1			

*Budgetary estimate following first round of cost reductions

+Class A only

the blast/fire experiments for MILL RACE and Workshop 2 considered the blast-structures tests proposed. The reports of these workshops (Chapter VI) describe the recommendations which resulted from these discussions.

(Note: Following the conference, and in response to the conference recommendations, revised Host Area Shelter, Key Worker Shelter, and Industrial Hardening experiments were submitted by SSI; revised experiments on Structural Response and Debris Translation and on Airblast Extinction of Fires were submitted by SRI. The Key Worker Expedient Shelter Test originally proposed by FEMA was retained for possible inclusion in MILL RACE, following analysis and, perhaps, design changes. Features of the remaining experiments originated by FEMA and WES and of an IITRI-proposed experiment on shelter survivability function development will also be incorporated in the FEMA field test program. A consolidated program, constrained by FEMA funding limitations, is to be submitted to DNA prior to 17 June 1980.)

DNA THERMAL AND BLAST/FIRE PROGRAM

The following viewgraphs from T. Kennedy's presentation outline a proposed, DNA-funded, 5-year research program. The first ten viewgraphs deal specifically with fires; subsequent viewgraphs describe the development efforts in thermal simulation.

DNA THERMAL PROGRAM

- FIRE SPREAD EFFORT
- FIELD FACILITY
- FLASH LAMP FACILITY

Critical Fire Questions

- WILL A CENTRAL AREA BURN OUT?
- WILL LONG RANGE IGNITIONS CAUSE EXTENSIVE FIRE DAMAGE BEYOND THE RANGE OF BLAST DAMAGE?
- WILL FIRES INITIATED IN THE BLAST AREA PROPAGATE INTO UNDAMAGED AREAS?
- WILL THE SYNERGISTIC EFFECTS OF FIRE AND BLAST REDUCE THE OVERPRESSURE REQUIRED TO KILL SPECIFIC TARGETS?

Some
Strategic Pro's & Con's of Thermal

PRO	CON
FIRE CAN INCREASE THE DAMAGE AND RANGE OF DAMAGE	THERMAL IGNITION IS WEATHER-DEPENDENT
FIRE CAN INTENSIFY THE DAMAGE IN THE BLAST AREA	DEFENSE AVAILABLE AGAINST SPREAD BEYOND BLAST AREA
THERMAL CAN EXTEND FURTHER THAN BLAST FOR LARGE WEAPONS	DEFENSE AVAILABLE AGAINST RADIANT IGNITION BEYOND BLAST AREA

CHARACTERISTICS OF NUCLEAR WEAPON INDUCED URBAN FIRES

- SIMULTANEOUS FIRE STARTS
- WEATHER NOT A MAJOR FACTOR
- HIGH TEMPERATURES AND GAS CONCENTRATIONS
- LARGE AREAS INVOLVED
- HIGH VELOCITY WINDS
- LARGE SCALE ATMOSPHERIC EFFECTS

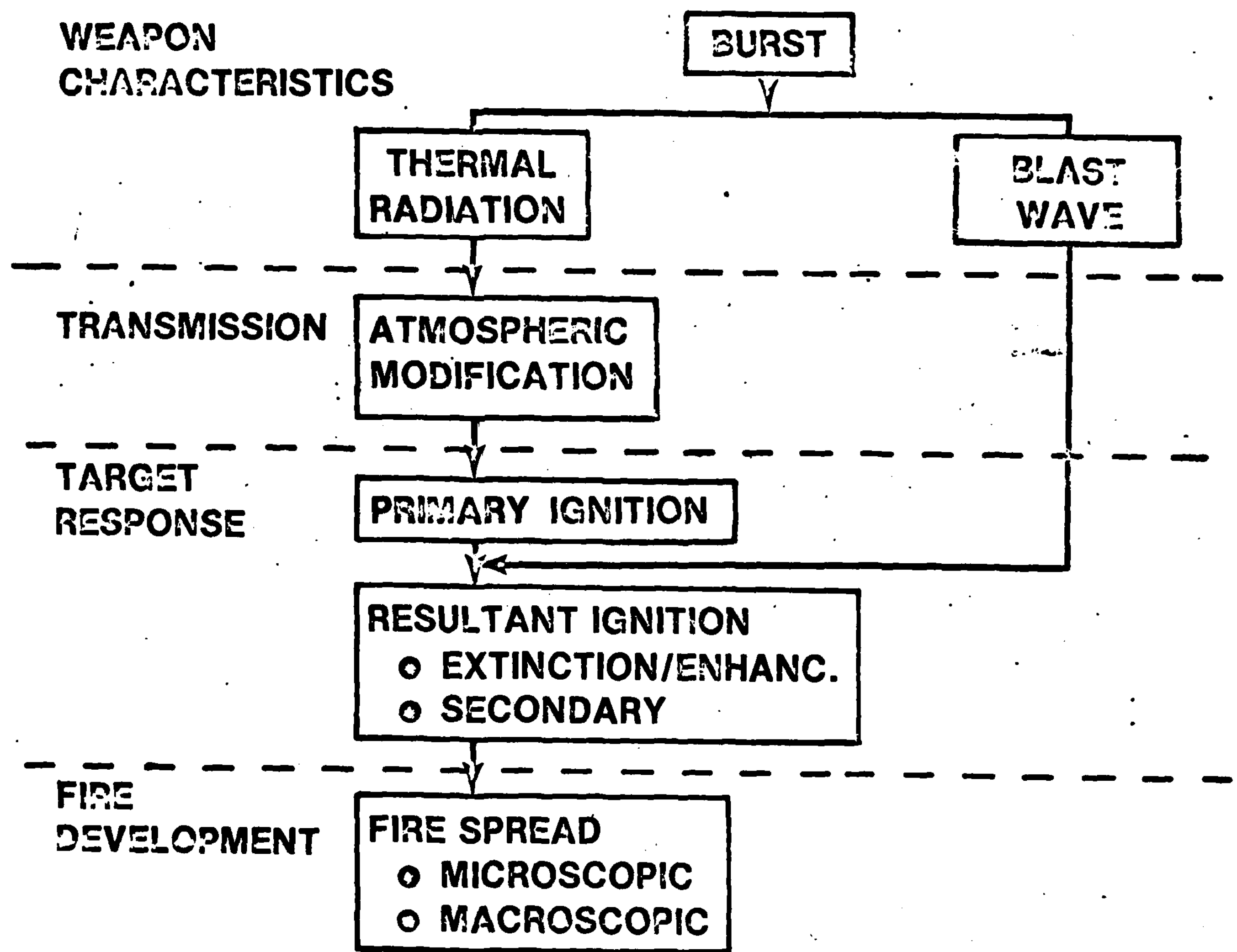
SPECIFIC INFLUENCING PARAMETERS

- THERMAL TRANSMISSION
- MULTIBURST
- FIRE DAMAGE MODEL
- BLAST-FLAME INTERACTION
- POST-BLAST FUEL BED
- IGNITION THRESHOLDS
- WEATHER EFFECTS
- LARGE-AREA FIRE-ENVIRONMENT
- PRE-BLAST FUEL ARRAY
- FIRE SPREAD

BASIC FIRE QUESTIONS

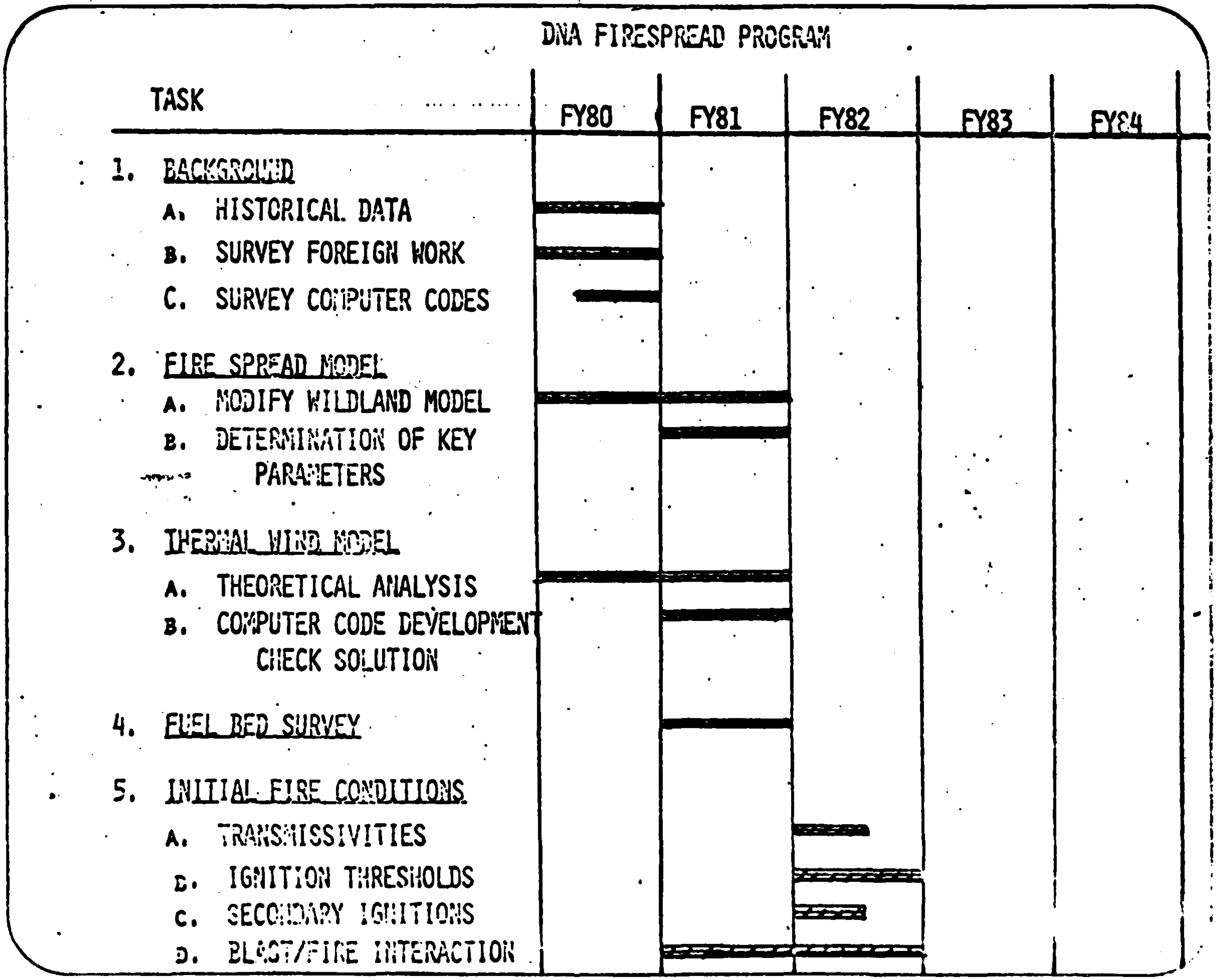
- WHAT IS THE INITIAL DISTRIBUTION OF FIRES FOLLOWING A NUCLEAR DETONATION?
- HOW FAST DO THE INITIAL FIRES SPREAD FROM THE AREAS OF INITIAL IGNITION?
- WHAT IS THE AMOUNT AND AREAL EXTENT OF THE FINAL FIRE CAUSED DAMAGE?

Fire Problem Flow

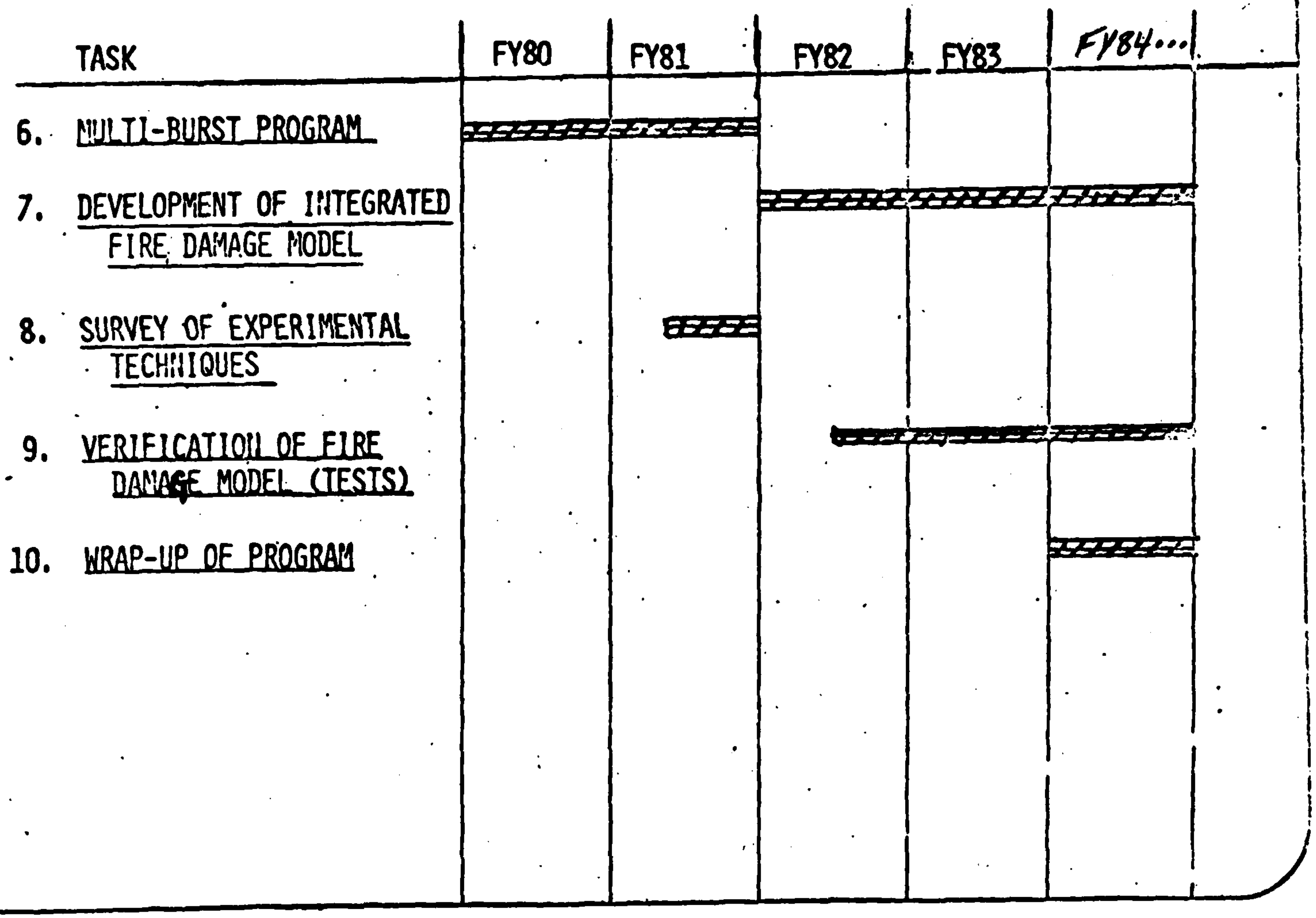


Status

WEAPON CHARACTERISTICS	ADEQUATE
TRANSMISSION/ATTENUATION	ADEQUATE
TARGET SHORT TERM RESPONSE	
o INITIAL IGNITION	CRITICAL
o SECONDARY IGNITION	POSSIBLE WITH PRESENT KNOWLEDGE
FIRE DEVELOPMENT	
o ROOM/BUILDING	ADEQUATE WORK UNDERWAY
o "MICROSCOPIC" GROWTH	CRITICAL
o "MACROSCOPIC" DEVELOPMENT	GROWTH RESEARCH REQUIRED FIRST


DNA FIRESPREAD PROGRAM
TASK
FY80
FY81
FY82
FY83
FY84
1. BACKGROUND
A. HISTORICAL DATA
B. SURVEY FOREIGN WORK
C. SURVEY COMPUTER CODES
2. FIRE SPREAD MODEL
A. MODIFY WILDLAND MODEL
B. DETERMINATION OF KEY PARAMETERS
3. THERMAL WIND MODEL
A. THEORETICAL ANALYSIS
B. COMPUTER CODE DEVELOPMENT CHECK SOLUTION
4. FUEL BED SURVEY
5. INITIAL FIRE CONDITIONS
A. TRANSMISSIVITIES
B. IGNITION THRESHOLDS
C. SECONDARY IGNITIONS
D. BLAST/FIRE INTERACTION

DNA FIRESPREAD PROGRAM (CONT.)



PROGRAM FOR FY80

TASK 1. SUMMARIZE FIRE DATA FROM WWII AND REPRESENTATIVE NATURAL DISASTERS.

TASK 2. EVALUATE APPLICABILITY OF ROTHERMEL WILDLAND FIRE MODEL METHODOLOGY TO URBAN ENVIRONMENT.

TASK 3. STUDY THERMAL WINDS PRODUCED BY LARGE AREA FIRE.

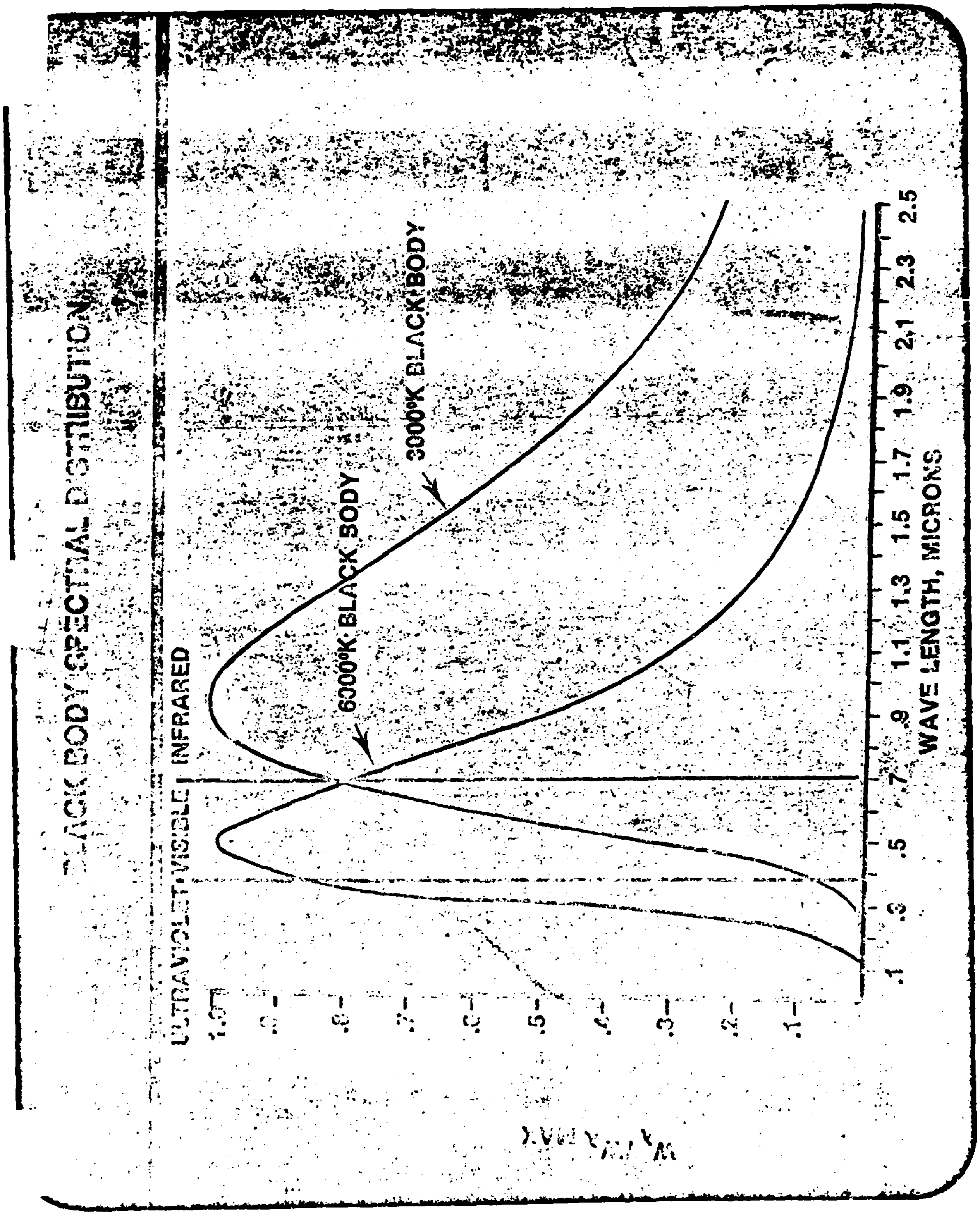
TASK 4. INVESTIGATE THE MODELING CAPABILITY OF EXISTING HYDROCODES COUPLED TO FLAME/HEAT TRANSFER MODELS.

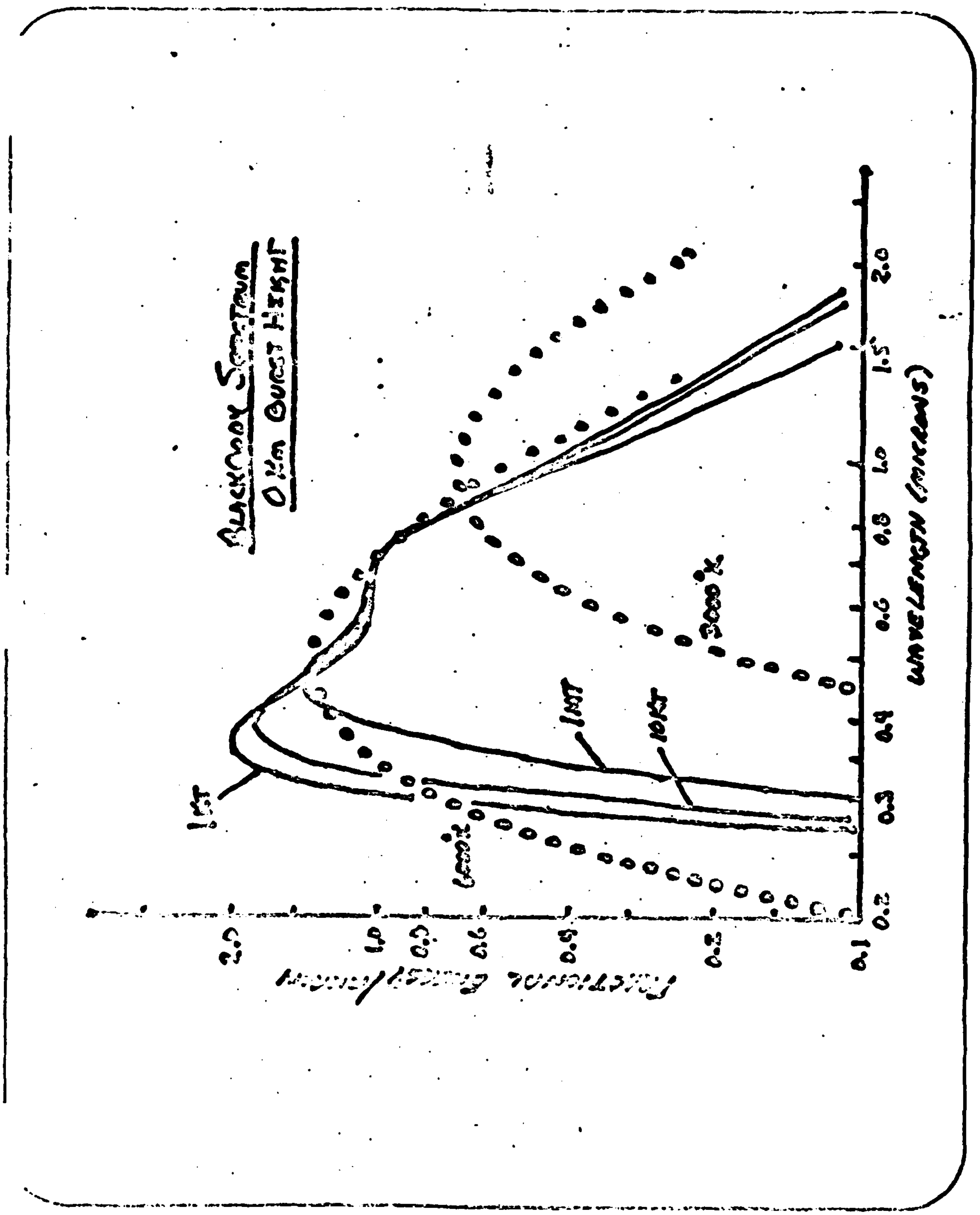
1 KT SURFACE BURST

GROUND RANGE (FT.)	FIREBALL ARRIVAL TIME (MS)	OVERPRESSURE (PSI)	SHOCK ARRIVAL TIME (MS)	FLUENCE (CAL/CM^2)	FLUX ($CAL/CM^2/SEC$)
100	3.4	3638	2.5	14	1350
200	21.0	478	14.3	10	840
300	143	168	37.0	35	2100
500	--	49	112	62	360
1000	--	11	409	24	11
2000	--	3.7	1190	--	--

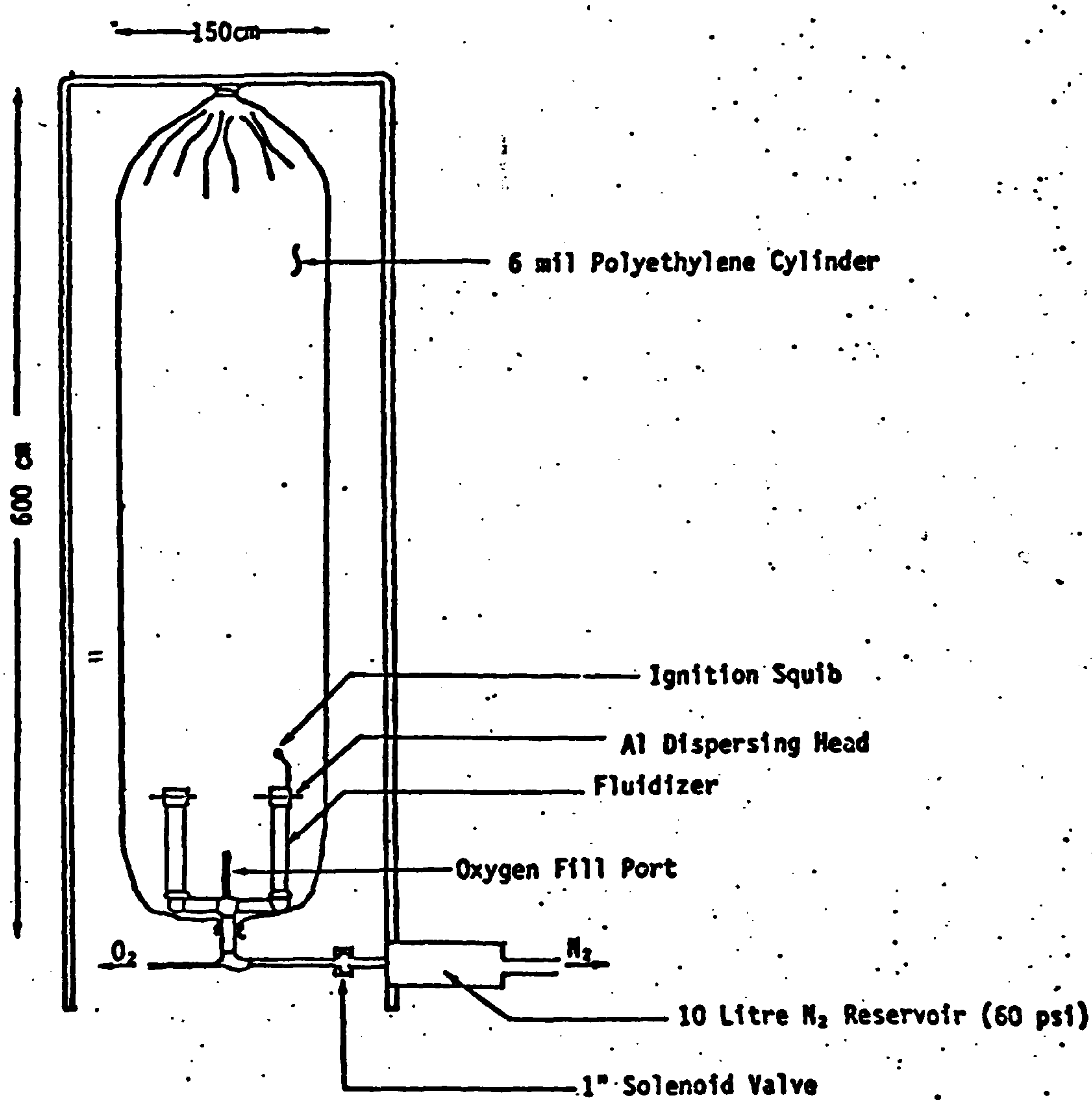
COMPARISON OF SOLAR FURNACE CHARACTERISTICS

SOLAR FURNACE	NOMINAL POWER (KW)	NOMINAL POWER (CAL/SEC)	(CAL/CM² SEC)	EQUIVALENT AREA AT HALF PEAK FLUX (M²)	EQUIVALENT RADIUS AT HALF PEAK FLUX (CM)	GAUSSIAN FWHM (CM)	TOTAL ANGULAR RANGE (DEG)
DOE/SANDIA-ALBUQUERQUE	5000	4.06×10^5	60	1.35	65	N/A	80
CNRS/ODEILLO-FONT ROMEAU FRANCE	1000	2.39×10^5	360	0.13	20	8.5	120V, 150H
DOE/GEORGIA TECH, ATLANTA, GA.	400	0.95×10^5	50	0.38	35	N/A	80
DOD/WHITE SANDS MISSILE RANGE NEW MEXICO	30	0.72×10^5	100	0.036	11	N/A	90

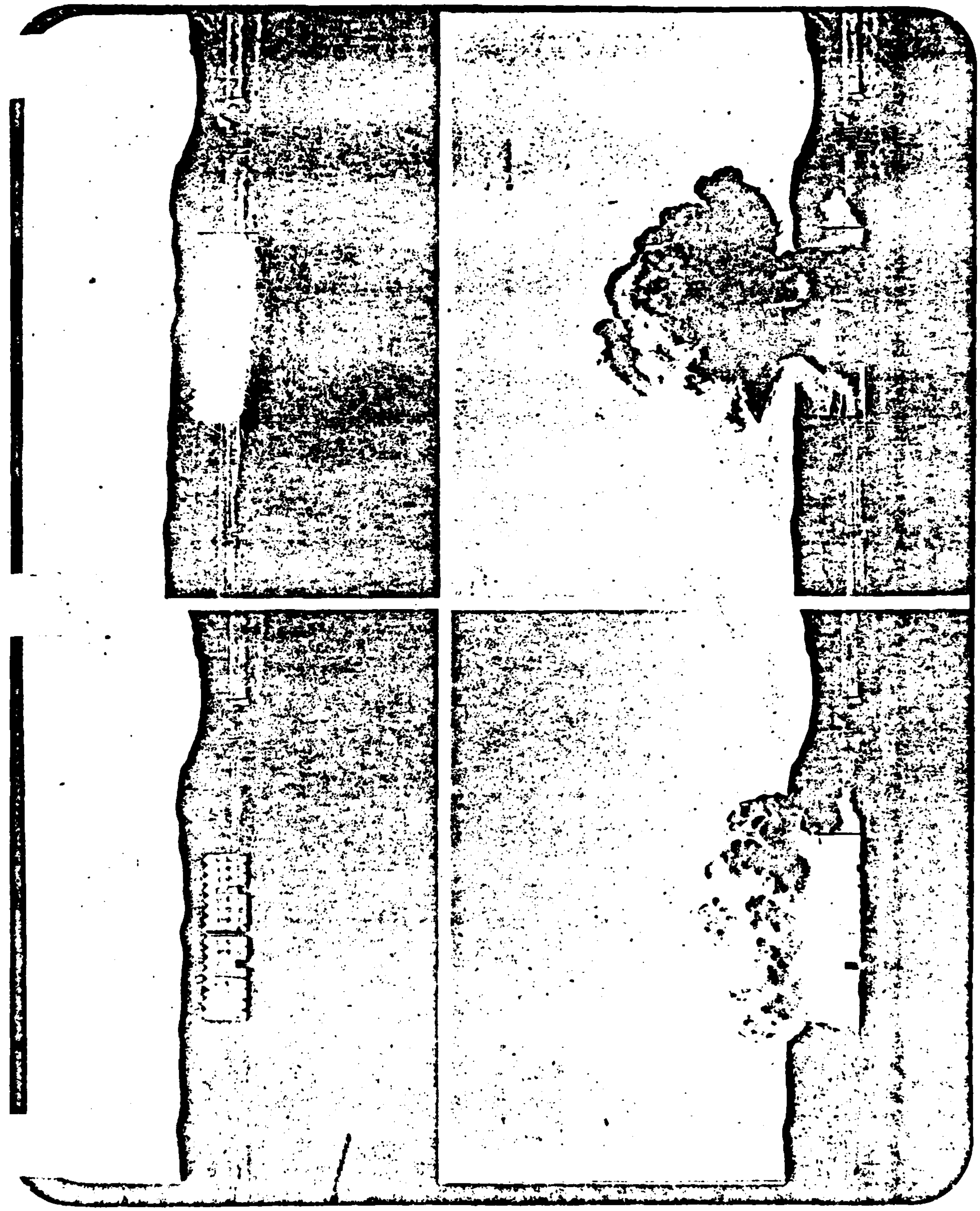

BLACK BODY SPECTRAL DISTRIBUTION
ULTRAVIOLET
VISIBLE
INFRARED
6000°K BLACK BODY
3000°K BLACK BODY
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.1
.3
.5
.7
.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
2.5
WAVE LENGTH, MICRONS



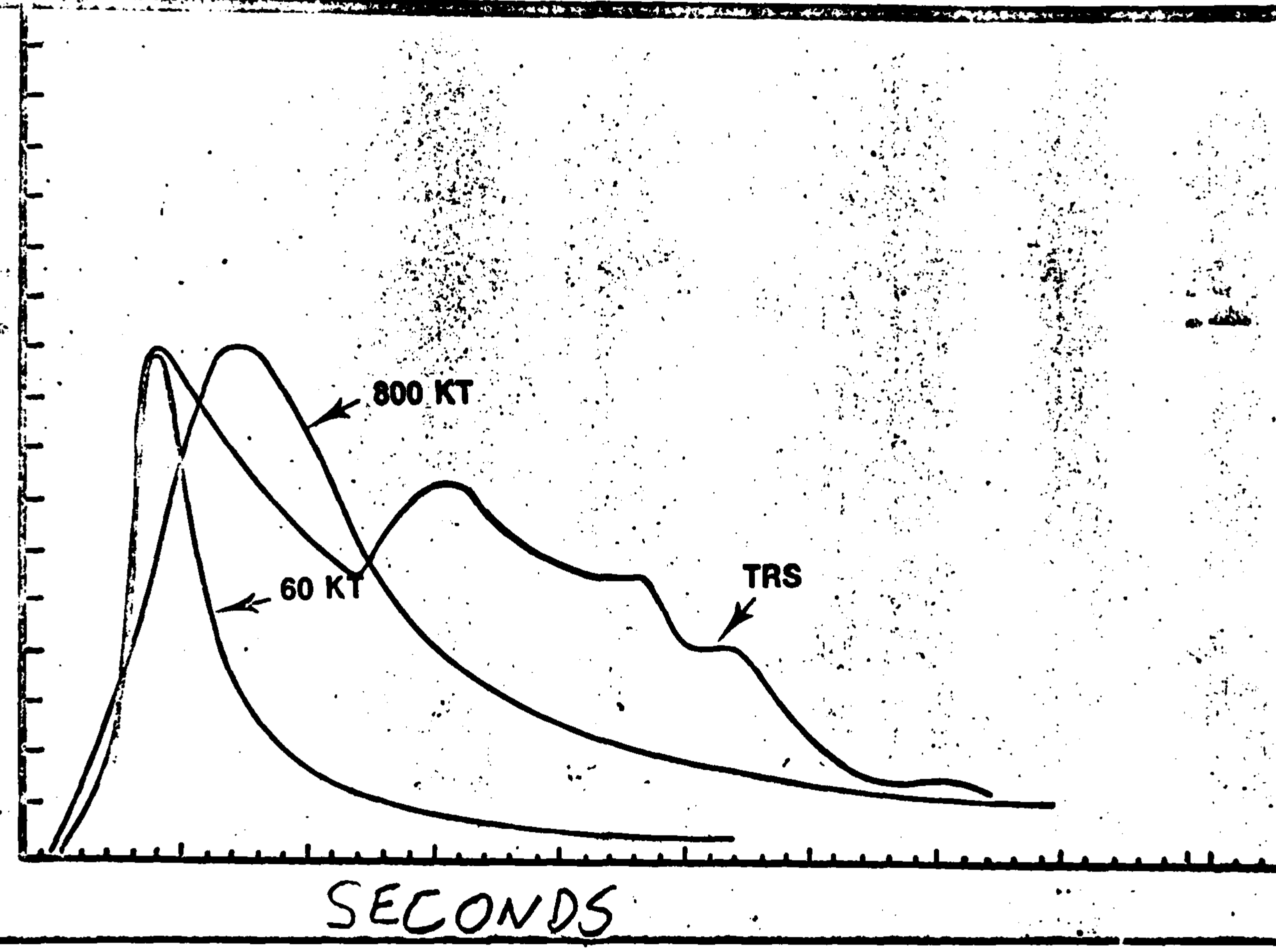
BLACKBODY SPECTRUM
0 Km BURST HEIGHT
1KT
1MT
10MT
3000°K
WAVELENGTH (MICRONS)
0.2
0.3
0.4
0.6
0.8
1.0
1.5
2.0
0.1
0.2
0.4
0.6
0.8
1.0
2.0

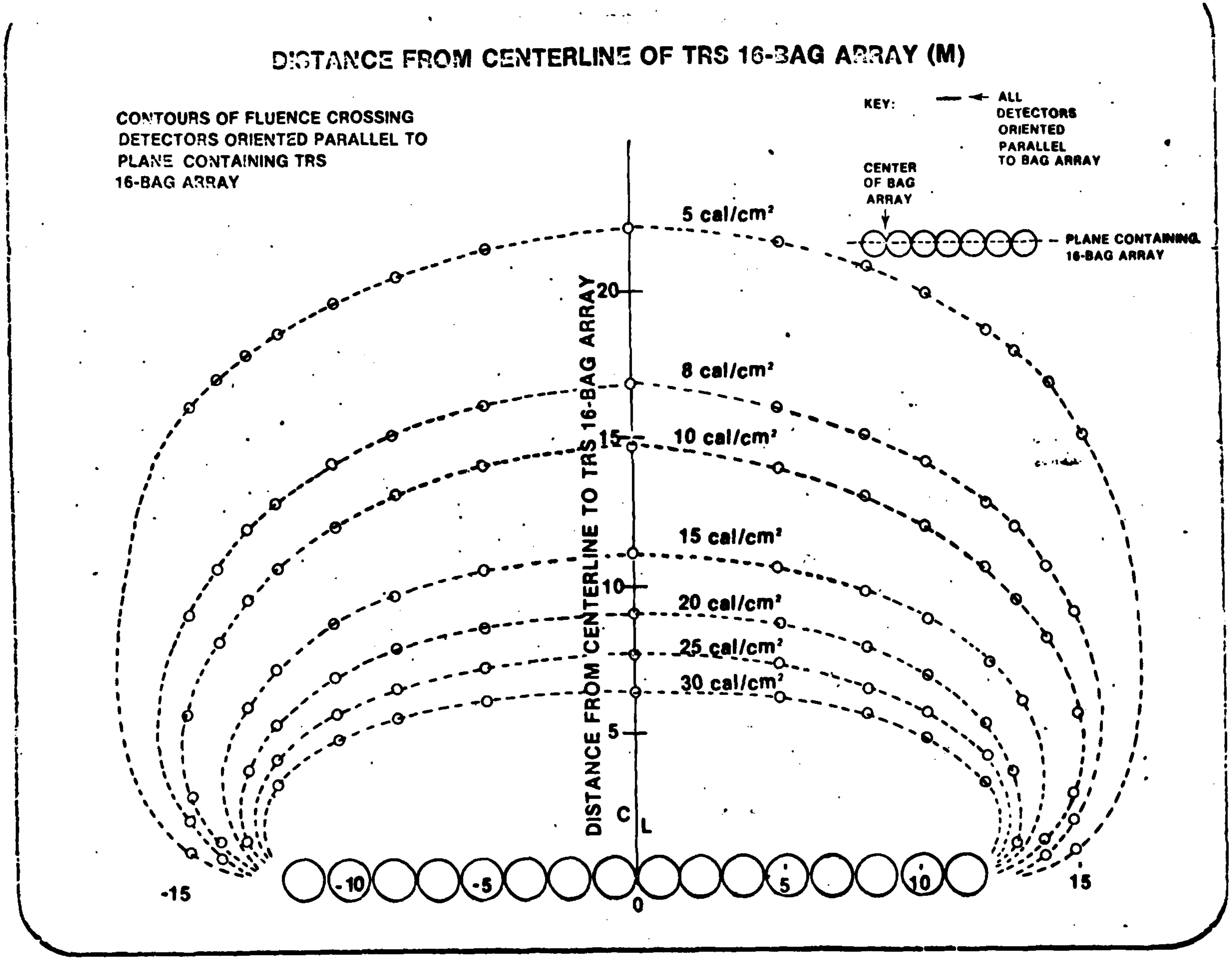


A Large C-System TRS Module

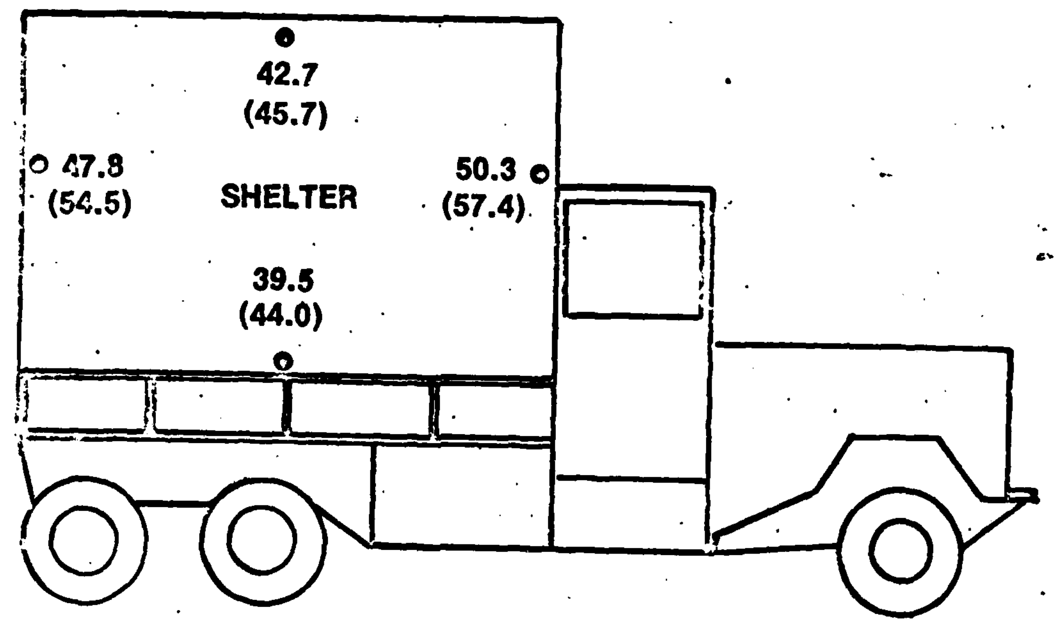


THERMAL POWER FOR TRS AND A 800KT NUCLEAR SOURCE



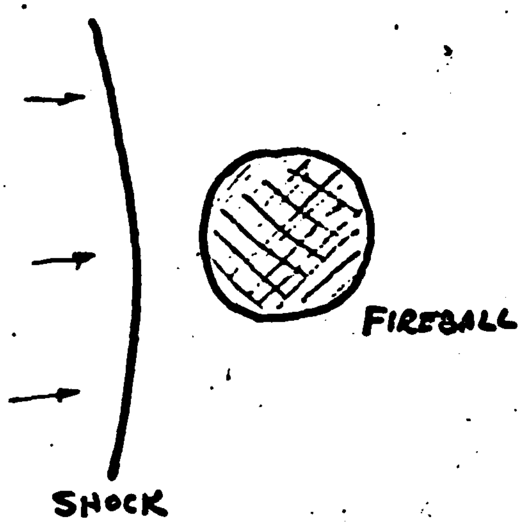

DISTANCE FROM CENTERLINE OF TRS 16-BAG ARRAY (M)
CONTOURS OF FLUENCE CROSSING DETECTORS ORIENTED PARALLEL TO PLANE CONTAINING TRS 16-BAG ARRAY
KEY:
ALL DETECTORS ORIENTED PARALLEL TO BAG ARRAY
CENTER OF BAG ARRAY
PLANE CONTAINING 16-BAG ARRAY
5 cal/cm²
8 cal/cm²
10 cal/cm²
15 cal/cm²
20 cal/cm²
25 cal/cm²
30 cal/cm²
DISTANCE FROM CENTERLINE TO TRS 16-BAG ARRAY
20
15
10
5
C L
-15
-10
-5
0
5
10
15

FLUENCE DELIVERED TO THE S-280 SHELTER ON THE MISER'S BLUFF EXPERIMENT

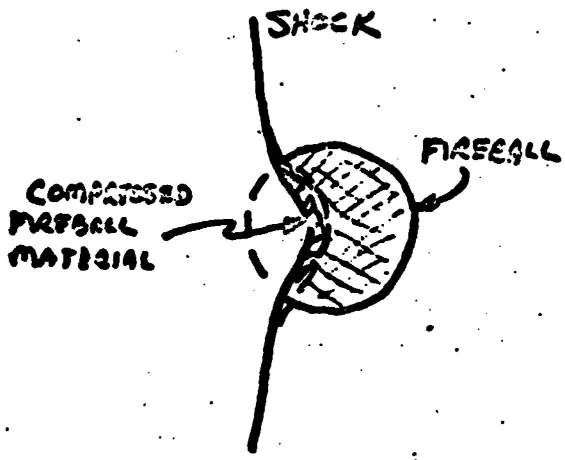


☆ Fluence at Shock Arrival - Cal/cm²

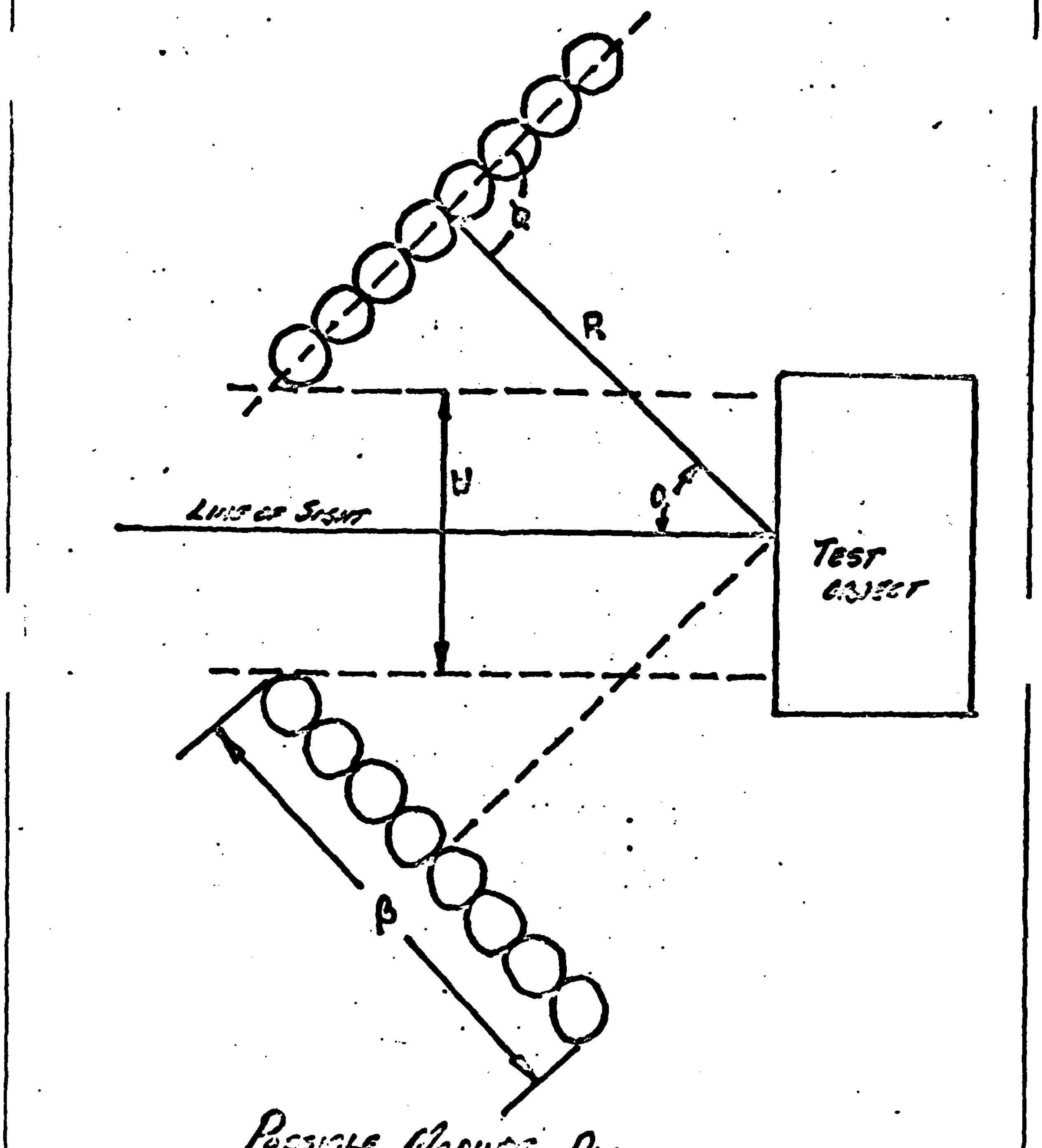
( ) Total Fluence Received - cal/cm²



PRIOR TO SHOCK ARRIVAL

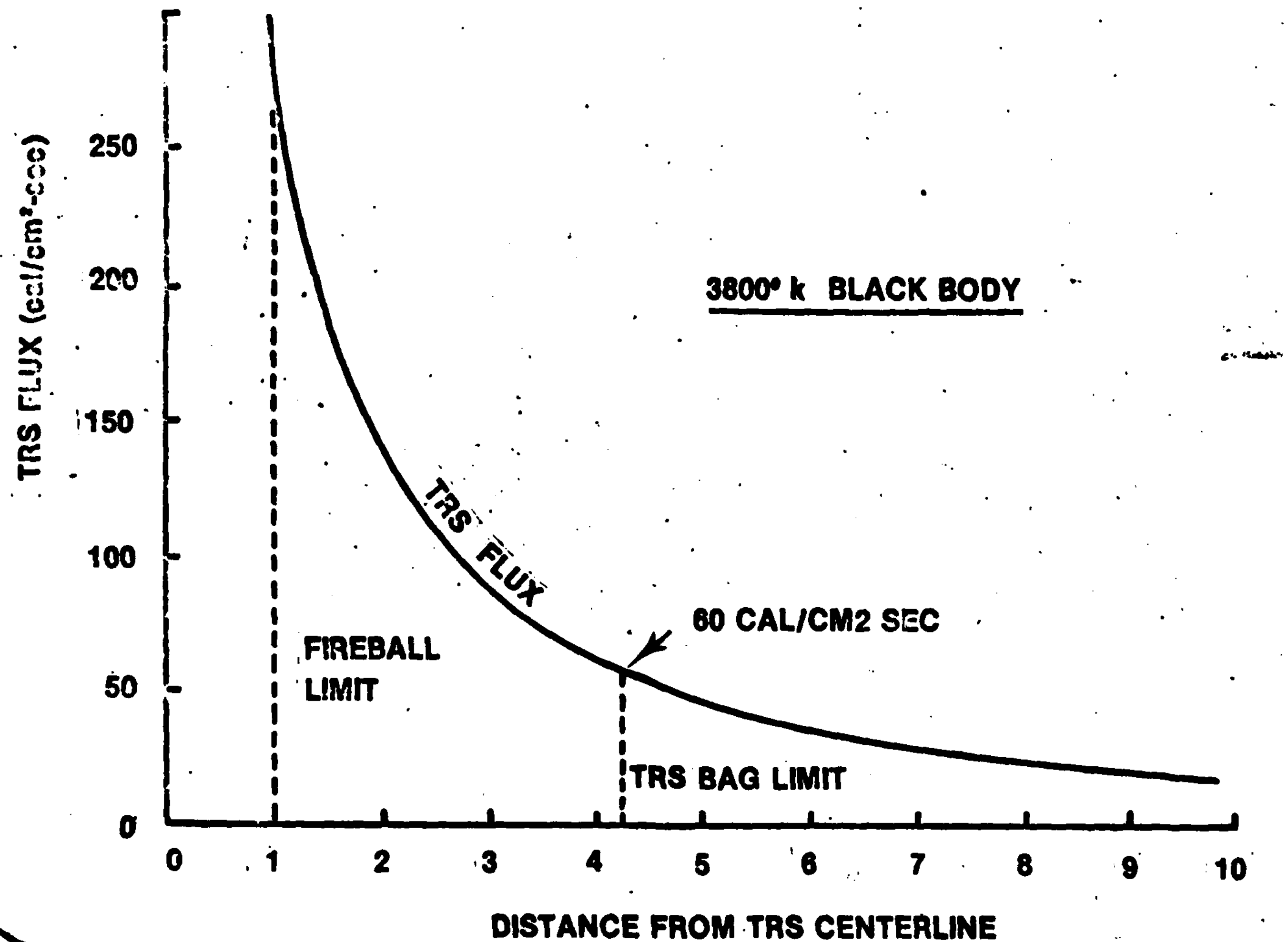


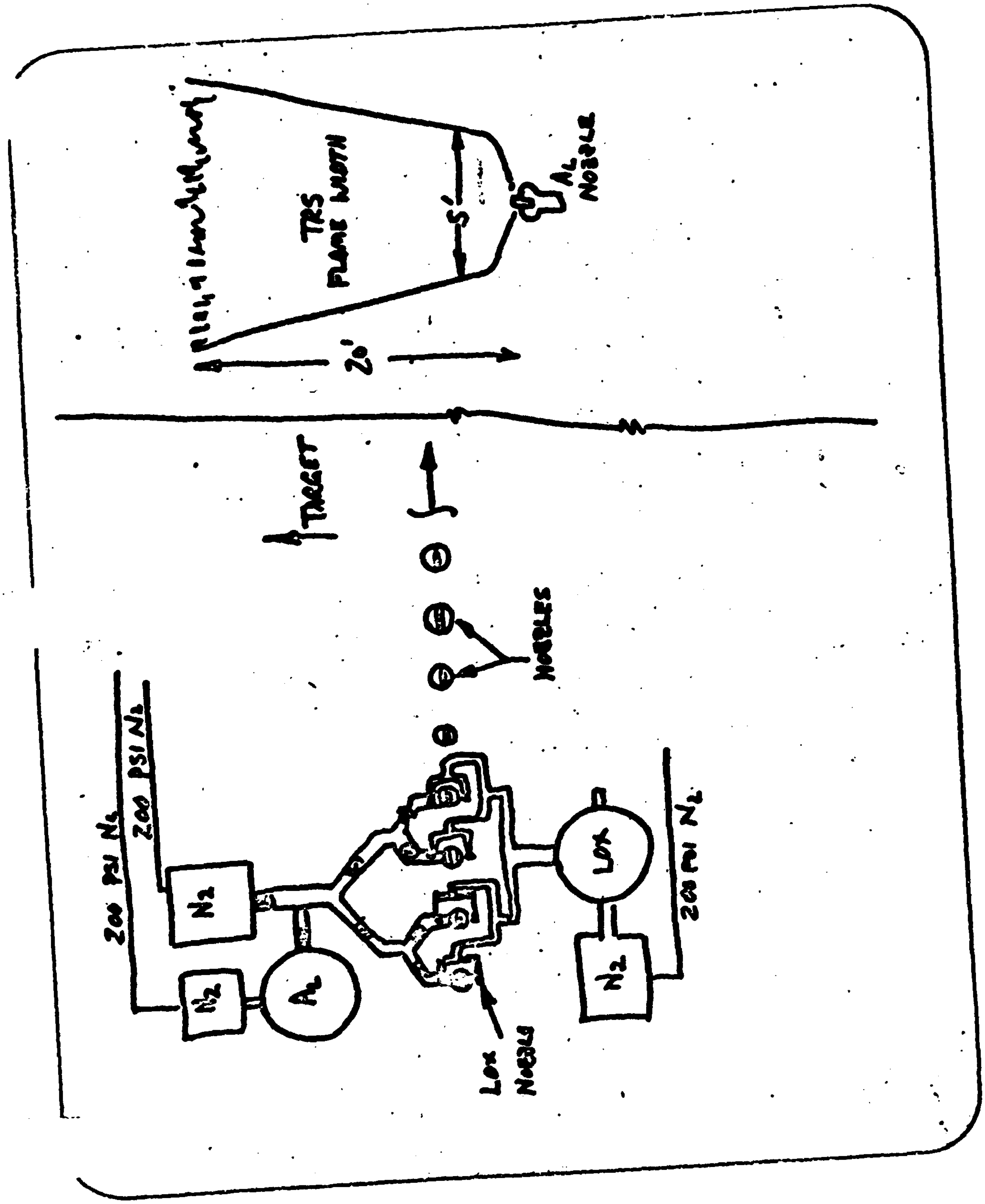
DURING INTERACTION



Possible Module Placement

ESTIMATED FLUX VS. RANGE

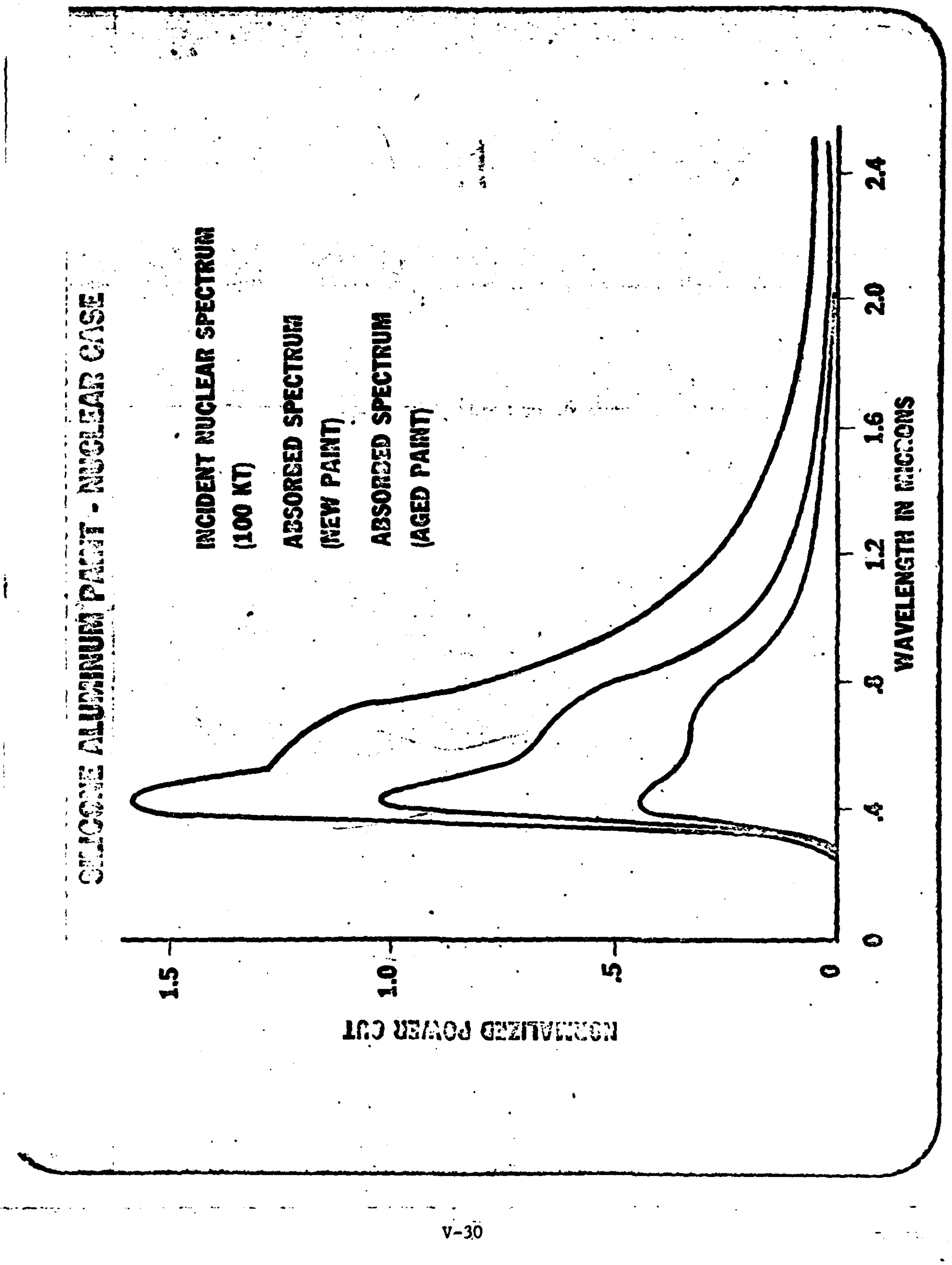




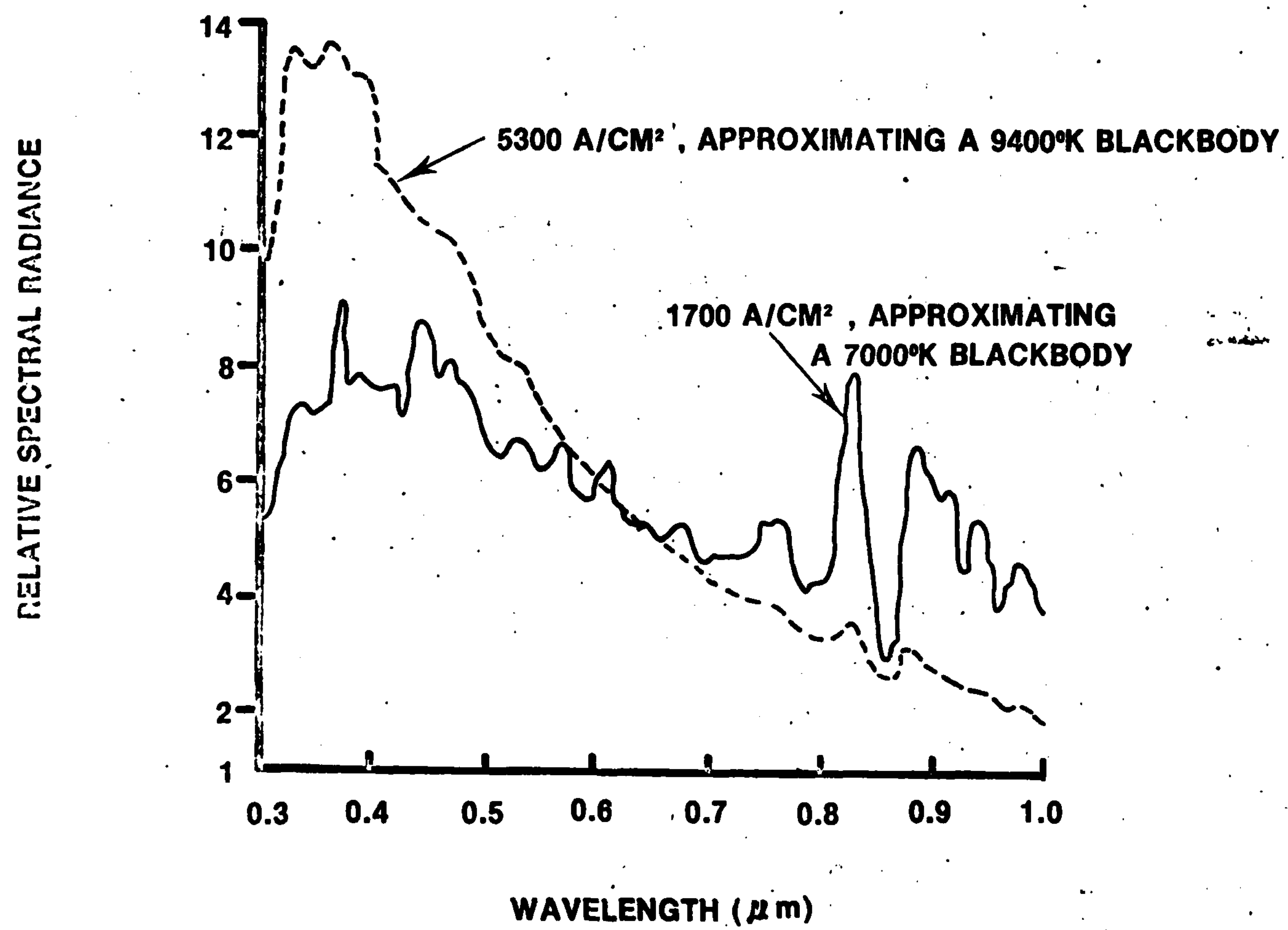
TRS
FLAME WIDTH
5'
20'
AL
NOZZLE
TARGET
NOZZLES
200 PSI N2
200 PSI N2
N2
N2
AL
LOX
200 PSI N2
N2
LOX
NOZZLE

COMPARISON OF RELATIVE ABSORPTION

NUCLEAR (FREE-FIELD) NO ATMOSPHERIC ABSORPTION (5 - 6000°K)	#17875 (WHITE)	#34201 (TAN)	#34079 (GREEN)	#34159 (GREEN)
• 1 KT	0.32	0.85	0.93	0.88
• 10 KT	0.28	0.85	0.93	0.88
• 100 KT	0.24	0.84	0.93	0.87
• 1 MT	0.22	0.84	0.93	0.87
• 10 MT	0.21	0.84	0.93	0.87
ESTIMATED TRS, NO ATMOSPHERIC ABSORPTION				
• 3800°K BLACKBODY	0.23	0.85	0.93	0.88

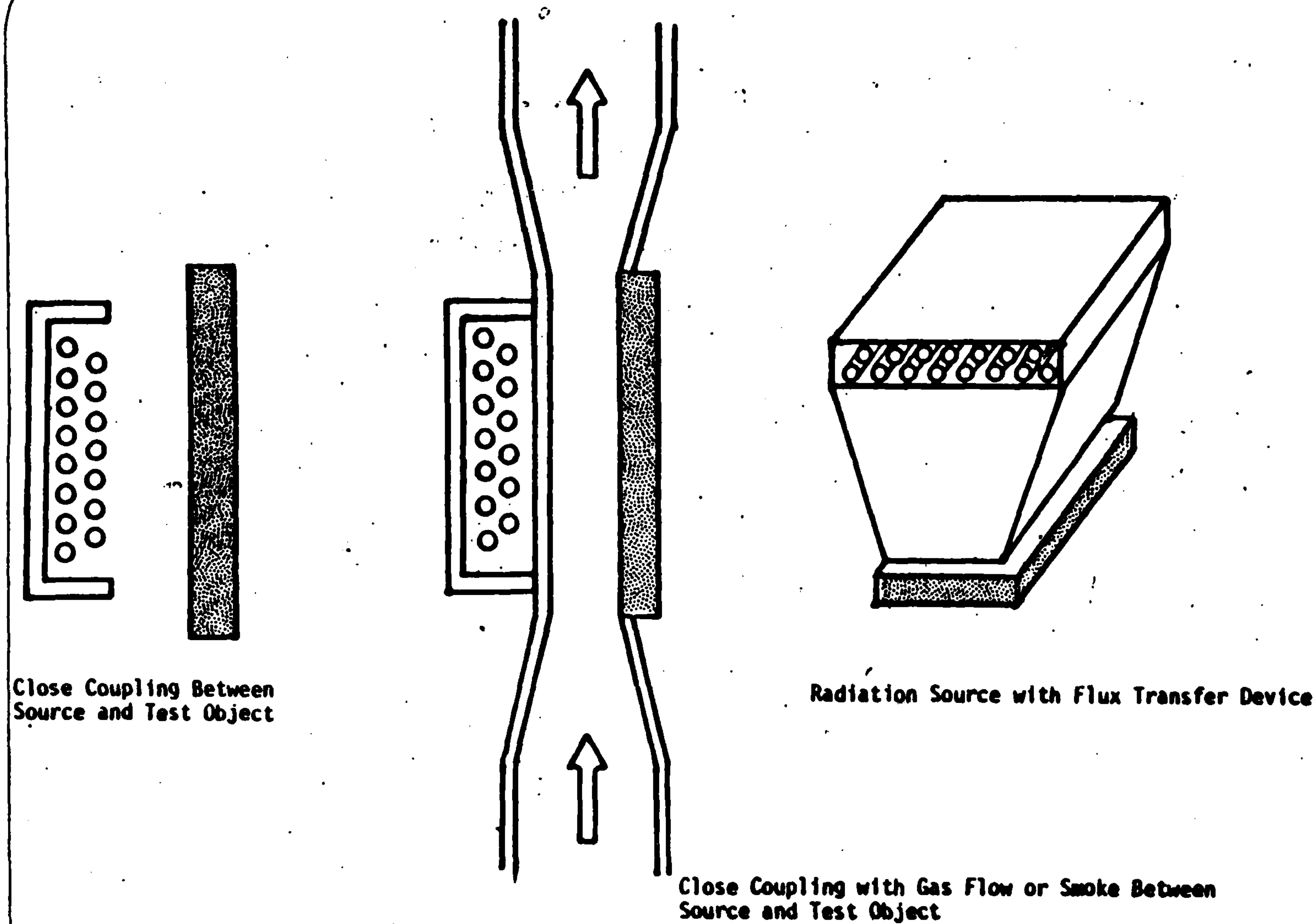

SILICONE ALUMINUM PAINT - NUCLEAR CASE
INCIDENT NUCLEAR SPECTRUM (100 KT)
ABSORBED SPECTRUM (NEW PAINT)
ABSORBED SPECTRUM (AGED PAINT)
NORMALIZED POWER OUT
1.5
1.0
.5
0
0
.4
.8
1.2
1.6
2.0
2.4
WAVELENGTH IN MICRONS

SPECTRAL OUTPUT FROM FLASH LAMPS CAN BE VARIED WITH OPERATING PARAMETERS



PERFORMANCE GOALS FOR NUCLEAR THERMAL SIMULATOR EMPLOYING FLASHLAMPS

PARAMETER		PHASE 1 MODERATE	PHASE 2 INTERMEDIATE	PHASE 3 FULL SCALE	
FLUENCE	(CAL/CM^2)	100	400	1600	1000
PEAK FLUX	(CAL/CM^2 SEC)	2000	700	700	1650
AREA	(CM^2)	100	100	100	
PULSE WIDTH	(SEC)	0.05	1.0	5	1
TEMPERATURE	(°K)	6000 - 7000	6000 - 7000	6000 - 7000	
ENERGY STORAGE	(MJ)	.3	.6	2.4	



Baseline Flashlamp Thermal Simulator

DNA HE TEST

- o MILL RACE
  - ▲ 600 TON ANFO DETONATION
  - ▲ WHITE SANDS MISSILE RANGE
  - ▲ AUG - OCT, 1981
  - ▲ POSSIBLE 5 TO 10 TRS 40 FOOT SOURCES

VI WORKSHOP ACTIVITIES

By and large, the workshops were structured along the lines evolved in previous conferences. Workshop 1 was charged with the responsibility to formulate research required for understanding and predictively modeling initial fire distribution, including the effects (on fire) of the subsequent air blast wave (or waves). Appropriately, initiation of secondary fire as well as primary fires is in the purview of Workshop 1. Workshop 2 continues to concern itself mainly with structures, structural response (to airblast), and debris production and distribution, all within a context of relevance to fire behavior and fire damage. Workshop 3 has the responsibility for research leading to improvements in predictive modeling of fire spread and overall threat of fire, with emphasis currently on critical facilities and key personnel. Workshop 4 continues to be concerned with fire countermeasures and fire intervention operations and strategies, again emphasizing critical facilities and key-worker protection.

Each workshop was required to summarize its deliberations and recommendations in written form. This chapter contains the workshop summaries.

Budgetary recommendations, given by only two out of the four workshops, are presented in contingency planning format. This provides, in addition to some budgetary norm, a low (or austere) level and a high (or optimal) level. It is suggested that these contingent levels be interpreted as they are subsequently defined in Chapter VII, Program Summary and Recommendations.

WORKSHOP 1: INITIAL FIRE DISTRIBUTION AFTER BLAST EFFECTS

The charge of Workshop 1* is to examine the initiation of fires by thermal pulse and any subsequent modification of them by the blast wave (including any secondary fire starts). Also included in the charge is the consideration of any new fire starts and further fire interactions caused by additional bursts. Specifically, the objectives are threefold:

1. Review and debate comparative merits of various avenues of investigation, including both theoretical and experimental approaches and analytical development of methods for interpretation of test results.
2. Appraise proposed blast/fire experiements for the MILL RACE event.
3. Review FY81 Program, update as appropriate, and formulate a Program for FY82.

This summary of Workshop 1 discussions at the 1980 conference has the following outline.

Introductory Comments

Formulation of Blast/Fire Interaction Problem

General Approach

Task Identification and Recommended Program for FY 1981

Individual Task Descriptions

Interactions with Other Workshops

FY 1982 Tentative Program

---

*Members of Workshop 1 were: A. M. Kanury (Chairman), J. Backovsky, H. Brode, J. Cockayne, P. Hughes, F. I. Laughridge, S. Martin, and V. Sjölin.

Introductory Comments

Discussion centered on methods to:

- Compare ignition of geometrically complex targets (e.g., edges, cracks, corners, folds) with thresholds established for simple targets.
- Investigate airblast angle-of-incidence effects, effects of enclosures.
  - MILL RACE may provide a good opportunity to see how the blast wave extinction effects are dependent on geometrical factors.
  - A solar furnace (in Albuquerque) may be useful for large-specimen ignition studies.
  - An enclosure designed to withstand airblast overpressures might be used experimentally to see how fire behaves within enclosed spaces under blast and/or thermal conditions (e.g., at the MILL RACE event).

Questions to investigate are:

Will fires start and persist? What are the conditions for thin or thick fuels?

How important is "nonideality" of surfaces? the ability of thin ignited items to ignite thick members?

Are debris piles easier to ignite with multiple bursts?

Would then a serious fire arise? following blast arrival?

Will the blast augment or extinguish the fire?

What are the mechanisms of extinguishment, reignition (non-extinguishment)?

What role does "local fire branding" play in redistributing initial ignitions?

Will debris pile up against walls?

What then is the fire distribution with respect to time and location? inside or outside rooms?

What is the relative importance of secondary fires caused by blast damage (e.g., gas pipes, petrochemical installations, debris pile-up on hot surfaces)?

Formulation of Blast-Fire Interaction Program

- Shocktube Studies--Plan shocktube experiments on rationally chosen geometries and fuels to:
  - Provide phenomenological observations (exploration)
  - Delineate the conditions of augmentation or extinguishment
  - Develop and test hypotheses of the mechanisms of extinguishment, repeat as needed (iteration)
  - Obtain data to verify theories (verification)
- Theoretical Models--Develop field equation and global scaling theories
- MILL RACE Tests--Plan field experiments to take advantage of large-scale blast wave, opportunity to "piggy back" on TRS experiments, and possible ambient wind fanning effects on delayed re-inflammation of smoldering fuel.

General Approach

- Exploration
  - Identify problem elements
  - Observe the physical phenomena to capture the overall essentials and to identify influencing variables
  - Conduct preliminary experiments
- Iteration
  - Hypothesize mechanisms--simple algebraic theories, order-of-magnitude estimates, dimensionless parameters
  - Conduct theory-testing experiments
- Confirmation (developmental) and Reiteration
  - Improve theory, seek correlations
  - Do experiments, correlations, interpretations (define hypothesis)
- Confirmation (full-scale verification) and Reiteration
  - Derive "operational" conclusions
  - Compare with the real thing (determine effects of scale).

Task Identification and Recommended Program for FY81

The discussion led to the following interactive scheme, Figure VI-1, relating various facets of the approach to the development of an operational understanding of the fire character before, and as effected by, the blast wave.

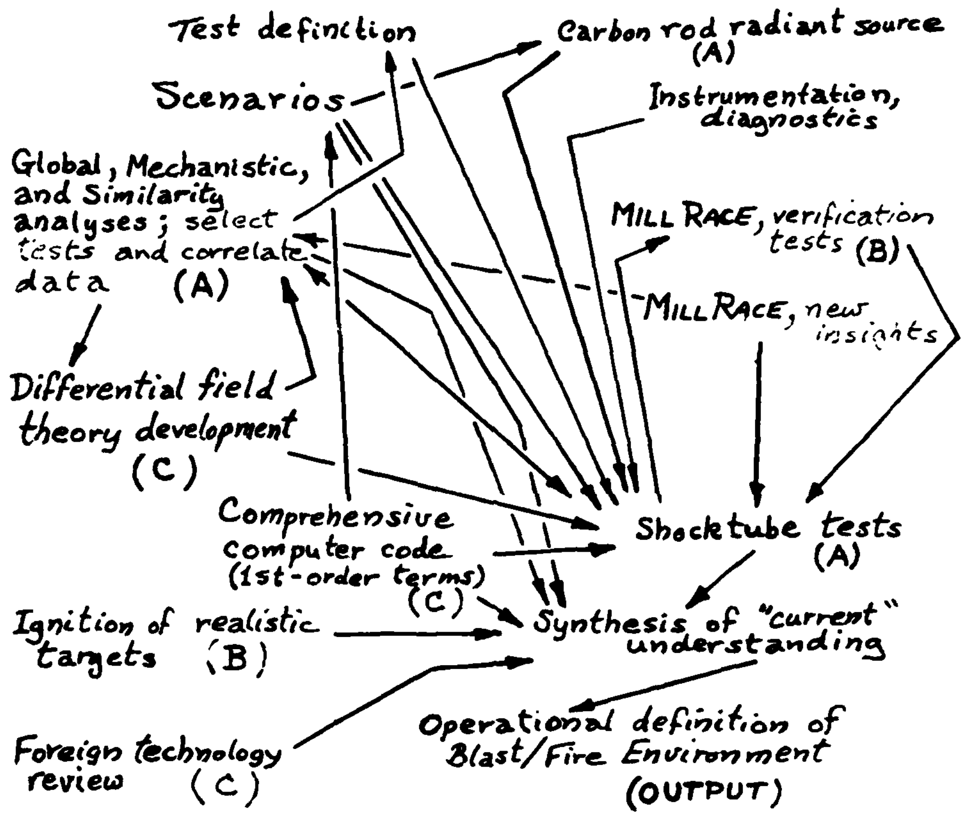


Figure VI-1 Task Interactions

(Letters in parentheses signify priorities)

Note that the shocktube experimentation of fire/blast interaction constitutes the focal point of this program at present. The overall objective of this workshop effort is to arrive at an operational (and conceptual) definition of fire initiation and fire/blast interaction, to be able to specify the density (i.e., time and space) distribution of the initial fires as a combined effect of the thermal radiation and air blast. Put in slightly different words, the objective is to answer the question: How many significant fires exist, and of what character, as a function of time and distance from ground zero as a result of a given nuclear explosion scenario?

The revised task items for FY 1981 deduced from this perspective are given in Table VI-1.

Table VI-1

FY 1981 TASKS REVISED

Priority[*]	Task No. and Title	Task Description	Recommended Budget (thousands) Austere[+]	Norm	Optimal[‡]
A	I-1. Shocktube Effort[#]	Experiments, data correlations and simulant development	200	250	300
B	I-2. Non-Shocktube Tests[§¢]	MILL RACE verification, non-CP tests[@] etc.	50	300	400
C	I-3. Theory of B/F Interaction	Field eqns. compputer codes, etc.	50	100	140
	I-4. Soviet B/F Literature Review	Obtaing of data, and theories	30	30	50
			330	680	900

[*] A is prime priority, B is next highest, C the next.

[+] The lowest practical level recommended.

[‡] Given the state of the art and the availability of technical personnel and tools, optimal progress is expected with the indicated support. Support in excess of the indicated is expected not to produce a proportionately greater rate of progress.

[#] Debris response to fires with and without multiple bursts to be treated in FY 82.

[§] Considerable debate occurred on the profitability of partaking in the MILL RACE event. Conclusion was that a few well-defined experiments to validate and to complement the shocktube experiments are desirable.

[¢] Large area ignition experiments can also be carried out at the CRTF solar furnace, operated by Sandia Laboratories, or the TRS facility, operated by DNA Field Command. Both are located at Kirtland AFB, NM.

[@] "Non-CP" refers to test activities conducted at locations other than SRI's Camp Parks facility.

Individual Task Descriptions

Task I-1 Shocktube Experiments with Associated Data Correlation and Simulant Development (Priority A)

Objective: Insight, conceptualization and test of hypothesis, and generation of a generally applicable data base on the interactive effects--enhancement as well as extinction--of fire with air blast.

Background

The shocktube facility, specifically designed for this objective, has been in operation for over a year. Emphasis to date has been placed on verifying the role of flame displacement as an extinction mechanism and scaling its effect with characteristics of the blast wave. These were also the objectives of the inconclusive experiments run in the field in 1972 at Mixed Company; thus, the shocktube experiments to date may be regarded as idealizations of the kerosene/gravel fuel beds at Mixed Company, but not simulations of blast/fire interactions accompanying nuclear explosions. The latter must await the availability of a suitable thermal-source accessory, such as the one presently under development by SAI.

Limited experiments in the shocktube with barriers and fuels of complex geometry demonstrate the strong and complicated effects of nonflat and other airflow-perturbing geometries on fire behavior; they also point to the limited practical applicability of the flame-displacement mechanism as a basis for theoretical development. This affirms the need for a fundamental understanding of the physics of compressible/transient fluid flow interactions with diffusional/unsteady combustion processes.

Program Subtasks

1. Shocktube Experiments: exploratory and systematic investigation of controlled-characteristic airblast waves with fires in both class-A and class-B fuels.

2. Analytical Support/Guidance: dimensional analysis (based on physical intuition) to define test variable matrix and provide data correlations.

3. Diagnostics and Simulants: identification, development, and integration of improved simulation accessories, techniques and instruments for determining properties of the airblast environment and its interactions with combustion processes and burning fuels.

Program Approach

1(a) Shocktube Experiments, Near Term--Workshop 1 recommends continuation of the research along lines already established. Effects of barriers and other perturbations to airblast diffraction and airflow should be investigated more fully with class-B-fueled fires, but work on practical configurations of class-A fuels should also be undertaken and pursued as rapidly as suitable fire-initiating sources are made available.

Some preliminary investigations are planned, using a laboratory-scale wind tunnel, to guide the selection of fuels for use in the shocktube. Liquid and possibly gaseous fuels varying widely in potentially pertinent properties (such as flame speed, mass-transfer number, stoichiometry) are to be screened by determining their air-flow-rate flame extinction thresholds under conditions of both steady and unsteady winds. Those fuel properties found to be associated with significant variations in flame-extinction behavior will then be included as principal variables in the shocktube studies through the selection of fuel candidates.

Fuel/air-flow configurational complexities are to be explored in the shocktube with both class-A and class-B fuels. An attempt will be made to quantify and generalize the barrier effect in terms of fuel properties and configurational variables (e.g., barrier heights and barrier-to-fuel-bed spacings). Well established wood-crib fires will be tested as representative of hard-to-blow-out fires. An attempt will be made to establish a reproducible, hard-to-extinguish class-A test specimen and to use this to determine an overpressure-duration matrix of extinguishment thresholds, as was previously done with hexane. Similarities and differences between class-A and class-B fires will be noted and explored.

1(b). Shocktube Experiments, Long Range--Much of the planning will have to await theoretical developments and simulant improvement. The more applied forms of experiments, being carried out now to get early answers, should be supported for long-term needs by a more fundamental experimental study of the physics of interaction of airblast with fire processes, using idealized target geometries and theoretically chosen fuels. Fundamental studies of this type can, nevertheless, be conducted in the present shocktube facility with minor investment in diagnostics. Such complementary studies have been proposed by SRI for funding by DNA.

2. Analytical Support/Guidance--Two sources of theoretical development to aid the experimental work are recognized: the on-going work unit at TRW (see summary of Work Unit 2563E), and a study being proposed by Notre Dame which is described separately below.

3. Diagnostics and Simulants--The workshop recommends early completion of the thermal radiation source accessory, under development by SAI, for use in the shocktube to provide controlled ignition of class-A fuels. This will permit a true simulation of the primary fire-starting process and allow the delay between ignition and shock interaction to be included as a test variable.

Last year's shocktube tests in which the airblast characteristics were at or near the extinction threshold for hexane-fueled flames exhibited a recursive up- and down-stream "struggle" of the flame to survive. A fuller understanding of this unstable behavior could be a key to understanding extinguishment mechanisms. Poor photographic visibility of the inside of the shocktube limits direct observation of such phenomena. Photo-optical techniques are being introduced to enhance the capability to observe flame motion and behavior. These will be supplemented with shadowgraphic techniques for observing shock diffraction and flow-perturbing effects. Other needed diagnostics include methods for measuring dynamic pressures and particle velocities.

4. Program Summary and Justification

In modern warfare, whether conventional or nuclear explosives are used, urbanized society often suffers collateral damage from counterforce or counterindustry attacks; cities may themselves be among the targets of strategic attack, as was the case in World War II. Fire was a principal cause of the destruction in the urban areas of Japan that were first to suffer the effects of atomic bombing. Unlike the immediate effects of a nuclear explosion, fire continues for some time to destroy property and threaten lives, and it may carry destruction outside the area of immediate damage, if conditions favorable to fire spread exist. Nevertheless, fire is potentially amenable to control, and much of its destructiveness is, at least in principle, subject to mitigation. Only its magnitude--both its extent and intensity (i.e., power density)--makes this prospect seem vain in the wake of a nuclear attack. Yet this magnitude remains quite uncertain, especially in the early stages of fire development, when countermeasures are apt to be most effective. The uncertainty is due, by and large, to many unknown interactions with air blast, including outright extinguishment. There is (fortunately) too little actual experience from which to draw reliable estimates. Depending upon the assumptions made, analytical estimates of the threat can range between the implausible extremes of relatively unimportant to totally unmanageable. The biggest of the currently recognized contributing uncertainties is airblast extinction.

The complementary experimental/analytical program outlined above offers a rational, achievable approach to a generally applicable technology that, once validated and enhanced in credibility through full-scale field testing, should reduce these uncertainties to an acceptable level for countermeasure evaluation. Hopefully, DNA will soon be able to support FEMA's efforts in this crucial research program area.

Task I-2: Non-Camp Parks Tests--Expedient Large-Scale Thermal and Blast/Thermal Experiments (Priority B)

Objective: Extend the state of knowledge in the general areas of (1) radiant ignition, (2) blast/fire interaction, and (3) reignition (or, nonextinguishment) in multiburst scenarios.

Background

A considerable body of knowledge has been assembled on the ignition characteristics of both thermally thin and thermally thick materials. In addition to the empirical data base, reasonably comprehensive and sophisticated theoretical models and predictive techniques are now being exercised.

Unfortunately, confidence in the theory is low in the following areas because there is insufficient experimental data to verify the theory:

- Large, complex and interacting structures.
- Thermal ignition and nonideal (enhanced) combustibles e.g., corners and folds.
- Mixed fuel ignition, e.g., post-blast debris.
- Large-scale room ignition and flashover immediately following radiant exposure through openings.
- Blast (overpressure and gust) interactions with radiantly ignited combustibles.
- Time-dependent reignition (or, nonextinguishment) of combustibles exposed to a single or multiburst thermal flash.

Some of these real-world, large-scale phenomena can be modeled theoretically; however, there are considerable gaps in the data base, and experimental work is direly needed. The SRI-built shocktube at Camp Parks is being used to extend the state of the art. It has, however, some practical limitations which necessitate the use of larger test facilities with free-field environments, such as will be provided by the MILL RACE high explosive event scheduled for September or October 1981.

Program

Development of a cost-effective experimental program is recommended to obtain the sorely needed data in the areas mentioned above, using test facilities that have large-scale or open environment advantages over the Camp Parks shocktube operated by SRI for FEMA. This program will be in concert, and coordinated, with the fundmental, controlled experiments being conducted at the FEMA facility.

Approach

The most cost-effective approach is to designate a coordinating organization from the experimental community, to serve as the focal point and prime mover in obtaining the lacking experimental data, largely by taking advantage of, and "piggy backing" onto other experimental opportunities. In many cases there will be opportunities to exploit the existing experimental environments, such as the DNA Thermal Radiation Source at Kirtland AFB, the Central Receiver Test Facility (CRTF) at Sandia, the Tri-Service Thermal Flash Facility at Wright-Patterson AFB, and the MILL RACE event at White Sands Missile Range.

A review committee from Workshop 1 should be formed and funded to (1) propose experiments, (2) review the appropriateness of proposed experiments, and (3) pass judgment on their design, comprehensiveness, and cost-effectiveness. Certainly this committee will need to know, early, the total funds appropriated for this overall research area, so that the return may be maximized and the proposed experiments may be prioritized. Some proposed experiments are as follows:

- Ignition threshold geometrical enhancement by corners, edges, and confined spaces and crevices, using large scale combustibles exposed to TRS environment (cloth, rug fabrics, overlapped wooden shingles).
- Debris pile ignition/blast extinguishment or reinforcement/reignition phenomena (including effect of rearrangement of debris as the result of repeated explosions).

- Use TRS with small shock-wave source, or use MILL RACE blast and thermal sources.

- Reignition source may be latent autoignition or 2nd thermal flash (multiburst simulation).

- Large-scale model room ignition and flashover experiment.

  - Model room with window and modern combustibles to obtain preliminary data on probability of initial fires and their intensity in the host areas where blast damage is very limited and fire will predominate.

  - Piggy back on TRS tests and consider next step after combined blast/thermal tests at MILL RACE.

Summary

The excellent shocktube, blast/thermal work must be augmented, verified, and extended by field test. This proposed work area will take full advantage of opportunities to piggy back on a variety of upcoming thermal and blast/thermal field tests. A review committee will screen opportunities and assist in planning experiments to capitalize on test opportunities and maximize the return.

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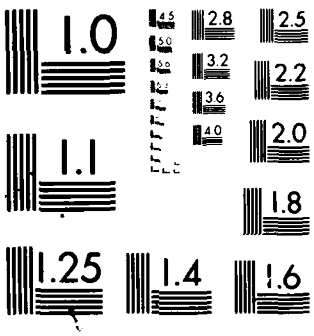

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

I-3 Theoretical Study of Blast-Fire Interaction

Objective: To develop theoretical models which would (a) lead to rationally designed blast-fire simulation tests; (b) be useful in interpreting, correlating, and extrapolating data and observations obtained from the necessarily limited number of shock-tube simulation tests; and (c) predict from first principles the behavior of flames and fires subjected to blast waves.

Background: The discipline of gas dynamics is a well-developed one in which the flow of gases is studied with full account taken of the compressibility effects and generally with ignored molecular transport effects of viscosity, thermal conductivity and species diffusion. The studies usually involve a characterization of the flow phenomena involving shock layers both with and without chemical reactions in the gas flow. Relatively little work is available, however, on shock waves propagating in nonreacting gas media and impinging on an otherwise 'ordinary' flame.

Some experimental work, however, is available on the topic of blast-fire interaction. Markstein at Cornell Aeronautical Laboratory studied the manner in which a shock wave would mutilate a spherically growing premixed flame of butane + air. Interesting photographic observations indicate the manner in which the front half of the sphere is folded inwards first to form a torus of a flame and then to penetrate it right through the rear half of the sphere. The penetrating front hemishere of the flame transcends into the form of a mushroom stem while the penetrated rear hemisphere of the flame becomes the cap of the mushroom, all in a matter of a few milliseconds.

The second available experimental work is that of the UCLA group of Tramontini, Simonsen, Dahl, and Guibert. In this work, burning forest fuel beds were subjected to blast waves from an air plenum. Experiments were conducted with exposure of the fuel beds to specified thermal radiation. The observations included the extinction thresholds. Some attempts

were made to correlate the experimental data on the basis of the premise that extinction is a result of convective heat and species dispersion rather than due to the gas dynamic effects of the shock.

Goodale's shock simulation tests at URS involved the interaction between kindling fires within enclosures subjected to blasts. A peak over pressure of 1 to 2.5 psi is required to extinguish all flames, this threshold being unaffected by the size of the window. The implication of this finding was that the convective flow perturbance alone is not responsible for the extinction process. Fuels which support smoldering were discovered in this work to continue smoldering even after the blast impingement, such smoldering eventually switching into flaming. In subsequent studies, Goodale employed overpressures as high as 9 psi to see if smoldering fires can be extinguished. No trend was evident, perhaps expectably. In a later study, the same investigator subjected burning curtains to low overpressure (1 psi) blasts, only to discover that transport of burning curtain fragments may become a considerable hazard under suitable conditions of; time of blast arrival; stage of burning of the drapes; weight of the hangings; etc.

Wilton and others also used the URS facility to discover that the extinguishment is influenced by the placement of the burning items relative to the openings of the room. Extinguishment occurred only when samples were situated in regions of high flow velocities such as at the doors and windows. No observations are evident regarding what happens in the recirculatory regions.

Some field experiments by Martin and Wiersma in the MIXED COMPANY involved wick-stabilized hydrocarbon fuel diffusion flames subjected to the shock wave of a 500-ton TNT explosion. The flames were found not to have been displaced from the fuel bed perhaps due to degradation of the shock wave near the ground. Exposure of synthetic and cellulosic cushions, held at an elevation from the ground, exposed first to a thermal pulse (fluence=20 cal/cm^2) and then to a 7 psi shock in the Misers Bluff study, lead to the belief that extinguishment has been accomplished of the flames started by the thermal fluence.

It is at about this juncture the simulation tests in the SRI shock tube have come to be, as designed, conducted and reported by Martin and coworkers. The most prominent of their findings lead one to believe that extinguishment of flames by blast is a result of flame displacement from the fuel bed. In recent work, there also exists evidence of an apparent augmentation of the flames by the blast.

Justification: When these above-mentioned various experimental studies and observations are considered together, it is clear that a coherent, consistent and complete understanding of the blast/fire interaction phenomenon cannot possibly be developed without a theoretical effort. Because of the multitude of physical, chemical, and geometric variables involved, even an idealized experiment cannot economically be repeated enough to cover a range of circumstances. The combinations of properties which represent practical situations of our overall concern are many. Add upon them the spurious and stochastic disturbances inherent to practical systems, one can only expect data of a dubious, fragmented nature to evolve out of these experimental studies no matter how carefully and thoughtfully they are devised.

Approach: Development of theoretical concepts promises to lead to a framework within the bounds of which the various pieces of experimental information can be fit into a sound perspective. The required theoretical efforts may be broadly placed into two categories:

- Similarity (or dimensional) analyses of candidate hypotheses of blast/fire interactions; and
- Fundamental studies on the response of idealized flames over beds of ideal fuels and geometries when an ideal blast impinges on them.

The first category of theoretical work will provide an integrated conceptual basis for the design and conduct of simulation experiments and correlative interpretation of the results. Based upon some of the known effects of blasts and of the attendant physicochemical phenomena on the behavior flames, several hypotheses of flame extinguishment and/or augmentation can be formulated. An examination of the variables involved will

then lead to a set of nondimensional parameters which would serve as scaling or similarity criteria to correlate the experimental data and observations. Most notable among the advantages of such correlation is the elicitation of the influence of different variables on the flame behavior in a composite and comprehensive framework. The combinational manner in which the various variables play a role becomes clear.

There are several ways of obtaining the relevant nondimensional parameters for a particular hypothesis. All the possible ways, however, possess the virtue that complete and rigorous mathematical solution is not necessarily required; only a judicious physical grasp of the problem at hand is needed. Once the parameters are extracted, correlation of the limited and costly experimental data will lead to a more complete understanding of the flame behavior than without the theory.

The second category of theoretical work involves formulating a hypothesis of blast/fire interaction; developing, from this formulation, the governing differential equations with appropriate boundary and initial conditions; and solving (as rigorously as needed) this mathematical model to arrive at predictions of the blast/fire interaction. The governing equations essentially involve the first principle equations of conservation of mass, energy, momentum and species. The transience of the interaction process, the imposition of radiant thermal pulse, the chemistry of fuel production (i.e., pyrolysis or vaporization) and of the combustion process itself, are some of the additions which complicate the classical fluid mechanics problem. Needless to say, the model involves partial differential equations. Idealizations are required not only in the problem formuation but also in its solution. Whether or not these idealizations are acceptable can only be judged from a comparison of the theoretical predictions with the experimental data.

It is obvious that the fundamental studies held great promise, but with a long-term fruition, to aid us in predicting and coping with the blast/fire interaction. On the other hand, the similarity analyses do not solve the predictive problem but aid in maximizing the impact and utility of the experimental data from simulation tests. Both the theoretical approaches appear to merit strong focus in the Blast/Fire Program.

Task I-4: Foreign Literature Review (Priority C)

Objective: Survey foreign--primarily Soviet-block--literature and research on thermal pulse ignition and blast/fire interaction to update and expand our present knowledge and data and to ensure effective use of research resources. Soviet shocktube facilities, uses, approach, and findings are of special interest in view of our significant efforts in that direction.

Background

For over 30 years, the shocktube has had wide use in basic and applied scientific research and in engineering, both in the U.S. and abroad. Both inert and combusting (burning or exploding) materials and environments have been studied in the shocktube. The purposes and applications have ranged from chemical-kinetic studies, to basic combustion and fuel flammability, to weapons effects. The Soviet Union has been a leader in the vigorous use of shocktube in combustion research, receiving, moreover, ample indigenous theoretical support, as well as the full benefit of U.S. literature. Shock-augmented combustion and shock/flame interaction have been studied, and a significant number of reports are available in the Russian language. Further, the Soviets have done work on thermal ignition of materials; their work on ignition of cellulosic materials has been addressed in earlier U.S. research on that subject and has probably expanded in scope in the past decade. Similar growth, primarily in sophistication of ignition methodology simulating nuclear thermal pulse, has occurred in the United States but was naturally limited in extent by funding. Other western countries may be interested in cooperation and exchange of translated literature: Sweden (through Dr. Vilhelm Sjölin) has shown keen interest in such an exchange, with regard to Swedish as well as other foreign literature.

Program Subtasks

Subtask 1--A brief survey will be conducted of present U.S. (and other English-language) translating services, their approaches, methods, and sources, of and other potential U.S. beneficiaries, i.e., other scientific committies or government agencies interested in the literature on foreign combustion, fire research, etc. The experiences of SAI, which has employed a Russian-language translator for its work--primarily on thermal ignition technology--will be tapped and explored for expansion and inclusion in this program. Past experiences of U.S. governmental agencies and such foreign abstracting services as the University of Karlsruhe's Center for fire-research literature will be examined to ascertain the most effective method for the present purpose. This is a start-up effort and will require about one-third of the total first-year effort proposed (1981).

Subtask 2--The specific needs of U.S. scientists working in the field of nuclear effects will be surveyed, defined, and prioritized, in concert with FEMA (and DNA) and its goals and policies. Possible cooperation, exchange, or cost-sharing will be identified. This task will be done concurrently with Subtask 1; together they will thus give the "what" and "how" of this effort. Subtask 2 will also be a start-up effort and will require about one third of the total first-year effort proposed (1981).

Subtask 3--A pilot translating effort will be run subsequently to Subtasks 1 and 2, with cooperation and criticism from the beneficiaries. The approach will be evaluated for its logic and cost-effectiveness, to be made fully operational and responsive to the needs of the community, starting with the second-year effort (1982).

Program Approach

This is a new direction within the FEMA program; therefore, the approach in the first year is necessarily exploratory. However, the method envisioned would produce (a) a somewhat expanded abstract as compared, for example, to those in the Chemical Abstracts, to be circulated

within the community, and (b) full-length translations on high-priority or specially requested topics.

Summary and Conclusions

In view of the limited research dollar, maximum use should be made of foreign work on the highly technical topics of blast/fire interaction and thermal ignition. Other topics beneficial for the FEMA program may be included, to be made available in translation.

Interactions with Other Workshops

Several interactive connections between the topics of Workshop 1 and three other workshops must (or certainly should) be kept in mind as a scheduling factor. Some of these are enumerated below in the form of relevant questions:*

Questions Requiring Output from Workshop 2--What are the target buildings composed of? How do they effect the fire incidence and growth? How do different structures come apart in response to blast? Where do debris fragments end up? and in what configurations, loadings, and distributions? What sort of flow velocities and patterns are involved in the room-filling process? Can scale models be used in a combined study of blasts and fires? How does the building modify the blast wave?

Questions Requiring Output from Workshop 3--What output regarding initial fire distribution is needed from Workshop 1 as input to Workshop 3? What connection is there between the intrastructural fire growth (with and without blast damage) and the initial fire behavior, on one hand, and the mass fire growth in the city, on the other hand? To what degree is mass-fire development dependent on the very initial, blast-affected fire distribution? When can structures be treated as independent of one another in the initial fire-growth process?

Questions Requiring Output from Workshop 4--The implementation of passive countermeasures is an input to the initial target description; what is reasonable to contemplate? Workshop 4 will need to know from Workshop 1 the time-dynamics of the consequences of the initial fire distribution, as perturbed by the blast, and as growth occurs, in making

*Editor's note: It is far from clear to us that either the inherent expertise of workshop members or any research activities they recommend will provide answers, in every case, to the questions posed here, within the foreseeable future. Nor is it necessarily within the purview of this research program to do so, since, as in matters of deciding national priorities before critical resources can be defined, the issues are often more political than technical.

decisions related to when to leave shelter, and what to expect on coming out. What form and level of detail should this take? A discussion of critical facilities and personnel has identified two sorts of criticalities--(1) critical in response, and (2) critical in impact. Such installations as industries involving solvents and other combustible chemicals are quite sensitive to thermal pulse exposure and blast loading. On the other hand, such installations as fire stations and communication centers, are critical in impact. Identification of the various critical facilities and personnel is needed from the countermeasures group. How should this interactive communication be effected?

FY 1982 Tentative Program

The recommendations for the FY82 program for Workshop 1 are shown in Table VI-2.

Table VI-2

TENTATIVE PROGRAM RECOMMENDED FOR FY1982*

Subject and Task Title	Task Description	Recommended Budget (K$) Opt.	Norm	Austere	Priority
Airblast Extinction					
Experiments in CP Thermal/ Airblast Facility	Investigate basic physics of extinction dynamics, seek generalized data correlations, test theoretical predictions	300	200	100	A
Non-CP Tests (e.g., BRL, Ft. Cronkite, Thunderpipe)	Supplemental to above	200	100	50	B
Post-MILL RACE	Analyze field event data+	100	75	50	A+
Theory development/ application	Modify as needed, postulate hypothesis for further test, extrapolate from data base	250	150	100	B
Enclosure and Fuel Complex Responses# HE and/or TRS Experiments (e.g., Kirtland AFB)	Fire initiation and early growth dynamics under best-available simulation and real-world configurations, multiburst scenarios	750	400	100	B‡
Predictive Model	Update existing model to current data base or results as needed, include results of secondary-fire study	40	40	40	[illegible]
One-City-Study Exercise	Apply predictive model to prescribed single-burst scenario, multiburst scenario	100§	75§	50§	A
Secondary Fire Dynamics	Improve the engineering data base for the secondary-fire model	100	50	30	A
Thermal Simulation					
CARRS Modifications	Develop improved spectral match, pulsing versatility	75	50	30	C
Field Sources	Improve TRS capabilities to suit special B/F research needs	400	200	100	D
International B/F Literature	Search for and review data sources (extension of FY81 survey of Soviet B/F literature)	75	50	25	C
Total		2390	1390	675	

*This program anticipates a substantial level of support from DNA to supplement FEMA funding.

+Requirement depends heavily on prior decisions about level of MILL RACE participation. If only class A extinction experiement is fielded, no requirement is anticipated.

#Results of activities recommended by Workshop 2 on debris distribution and building damage are prerequisite.

‡Becomes A if deferred until FY 1983.

§Predictive model update is prerequisite. Budget figures assume separate funding of update and timely availability of updated model for this application.

WORKSHOP 2: BLAST/SHOCK EFFECTS ON STRUCTURES AND OTHER CRITICAL ELEMENTS

Workshop 2* was interested in the response of structures to air-blast loadings only as a basis upon which to build a prediction technique for blast-wave interaction with structures and their contents, because the interaction can radically change fire initiation/growth/spread conditions.

Critical technical deficiencies, such as missing data and untested situations, were identified again (as they were in the 1978 and 1979 conferences) and updated; especially important was the consideration of field experiments that could be added to DNA tests already scheduled.

Key items of concern to this workshop and in need of further work are:

1. <u>Research Tasks</u>

   Single Building Studies
   Multibuilding Studies
   Building Contents Debris
   Building and Industrial Records Preservation
   Multiburst Effects/Response
   Upgrading of Existing Structures (Key-Worker Shelters)
   Casualty Estimation (People Survivial)
   Field Testing (HE)

2. <u>Research Program Recommended</u>

   Analyze City Complex (Crude Cut)
   Key Worker Shelter Studies
   Debris Formation, Translation, and Interaction
   Casualty Estimation (Personnel Survival)
   Frame Response of Shelters for Key Workers and Others
   Modifications of Blast Wave Characteristics in Urban Areas

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*Members of Workshop 2 were: C. K. Wiehle (Chairman), H. L. Murphy (Vice-Chairman/Recorder), G. Coulter, W. L. Huff, N. Iwankiw, K. Kaplan, T. E. Kennedy, A. Longinow, M. K. McVay, R. E. Peterson, J. R. Rempel.

3. Complementary Research Efforts

- Debris
  - Translation, Interaction, Mixing
  - Correlation Test/Analysis
  - Catalog
- Air Blast
  - Interacting Flows
  - Multiroom Flows
  - Oblique Incidence
  - City Complexes
- Structural Response
  - Frame Response/Collapse
  - Wall Behavior
  - Floor Collapse Criteria
  - Roof Response/Collapse
  - Upgrading Structural Elements
- Biomedical Data
- Engineering Method for INR (Initial Nuclear Radiation)
- Scale Model Use
  - Structural Response
  - Debris
  - Fire

Each of the above Research Tasks is discussed below, as is each of the Research Program items (in the form of Scopelets); the latter are listed in order of recommended priority and each is intended to stand alone. Figure VI-2, developed for the 1978 conference and used again in the 1979 conference report, is used once more. It is the consensus of the workshop members that the current state-of-the-art is adequate for immediate accomplishment of the first two tasks shown in the figure (as was also reported last year), with the second item to be undertaken in meetings of an ad hoc committee assisted by a recorder.

Except for the updating provided herein, the Workshop 2 reports of the two previous conferences (1978 and 1979) are generally unchanged,

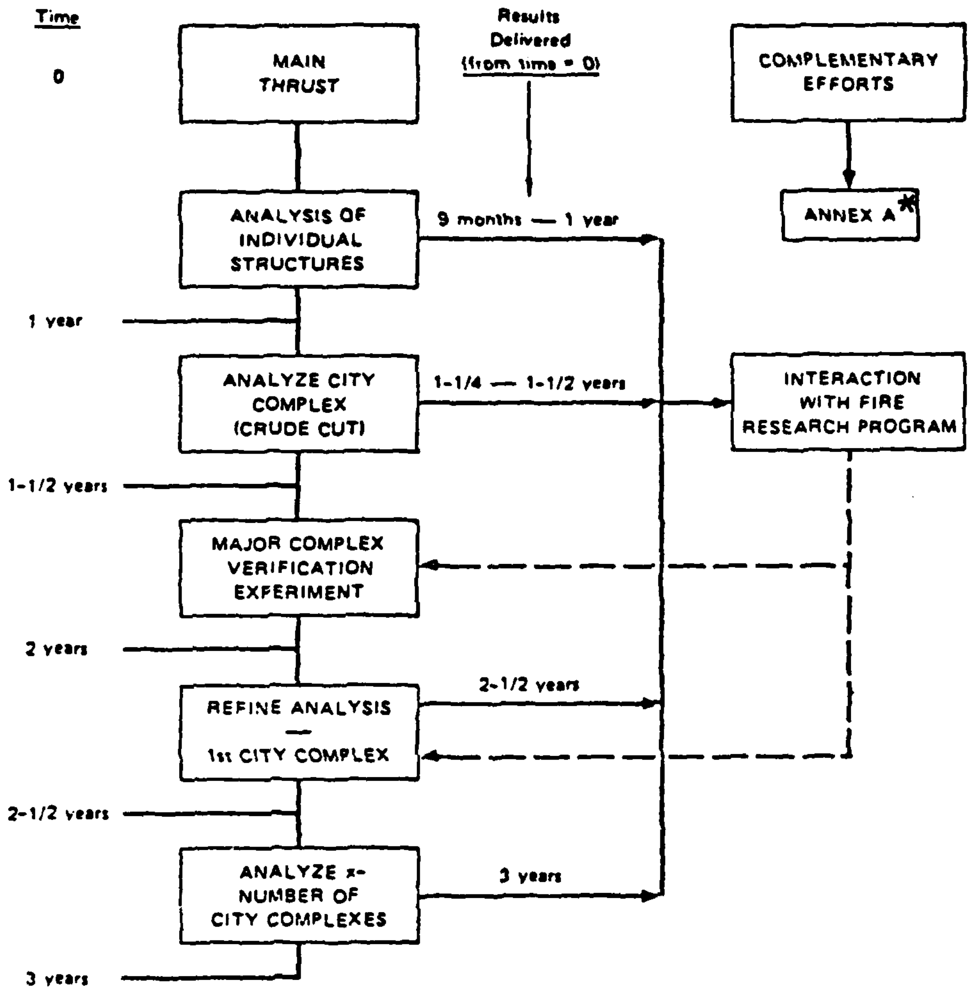

Figure VI-2   Blast-Structures-Debris Research Program

* See 1978 and 1979 FEMA Asilomar Conference reports.

because little research toward the goals/tasks previously set has been accomplished.

Single Building Studies

The structural response of single buildings subjected to airblast loads from nuclear weapons needs to be known if the buildings are to be used as shelters. Types of buildings that are potential shelters in both the host area (less than 2-psi*) and where key-worker shelters might be located (30- to 50-psi range) need to be studied.

Many state-of-the-art analyses have been developed that can now be used to predict the dynamic response and collapse pressure of various building elements. Many of the analyses have been verified with experimental data. (One exception is that the response of basement walls to large dynamic pressures through soil has not been tested beyond minor cracking, certainly not to collapse, or even approaching collapse. Recommended tests are discussed further under "Upgrading of Existing Structures.") These programs have been used with blast-loading techniques to predict the collapse of elements in a variety of National Shelter Survey (NSS) buildings.

Besides the strength of the individual building elements, the response of the entire building frame and how it collapses is of interest, especially how the collapse of the building frame might influence the safety of the shelter in the basement and what problems the debris might cause. Computer programs are available to analyze the elastic and inelastic response of multistory building frames, but they do not include collapse mechanisms. Programs need to be developed that could predict problems caused by frame collapse. There has been some work on roughly predicting the amount of debris resulting from collapsing building

*FEMA policy is to locate host areas where they are expected to lie outside this range; however, a policy exception is sometimes necessary, thus extending research/application interest to the "less than 3-psi range" (e.g., special situations where availability of vehicle routes and host communities, plus mountainous terrain, so dictate, such as host areas for the greater Los Angeles basin).

elements, but, because of the unknowns in the loadings on each wall of a building of complex geometry, the problem can only be bounded and not solved explicitly. Some computer analyses have also been developed to predict the translation and final disposition of debris produced by collapsing building walls. These programs require input in the form of the wall velocity at collapse and the size of fragments. Some tests have been planned in MILL RACE to experimentally verify predictions of these programs.

Many closure concepts have been developed in previous studies, but only a few closures have been tested.* The fact that key-worker shelters could conceivably be located in the 30- to 50-psi range is a new criterion. The design strengths of these closures must be greatly increased, and the closures should be tested to verify their hardness and checked for leaks.

Another area to be studied further is the environment inside the shelter including such matters as leakage of blast that can result in rapidly or slowly rising pressures, protection from radiation, excessive heat conducted to the basement, and introduction of fire into the basement.

Multibuilding (Especially Industrial Structure) Studies

Some marginal progress in the extension of single-structure blast-loading information into a city complex has been made but not yet realistically accomplished. Previous studies used models of structures of uniform size.

New work is needed to investigate nonuniform-sized structures (shadowing), blast-wave propagation down streets (channeling), and other blast and radiation effects that could influence structural loading, debris interaction and distribution, and fire ignition and spread within a city. Proven tools are not available, but some estimates can be made.

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*Test reports on small to vehicle-size closures should be reviewed early in any research effort, e.g., those from PLUMBBOB, TEAPOT and even earlier nuclear tests, as well as recent BRL shock-tube tests (wood).

Because of concern for urban key-worker shelters that could provide protection in the 30- to 50-psi range, multibuilding studies are needed for these higher overpressures, to address the problems of building frame collapse and its effect on shelters; debris formation, transport, and impact; the structural adequacy of basement walls and closures; and other structural problems that may surface.

Building Contents Debris

The distribution of building contents caused by an entering blast wave can be predicted for certain tested situations and estimated for certain idealized situations. If the only opening to a room is in the wall that is struck head-on by the blast wave, the subsequent flow (including entrainment of light debris within the room) can be approximated by existing methods. These methods include mathematical analysis (HULL and/or simple roomfilling), verified by reference to results of past experiments (URS tunnel, BRL model basement, and DICE THROW German residential structures 1 and 2). This information may also serve to describe the flow adequately for purposes of predicting extinguishment of primary fires and creation of secondary fires in certain relatively idealized situations.

However, when the openings are in different walls, or the flows are through connecting rooms, the analyses are appreciably more complex, and new analytical methods will be needed to handle the situations involving intersecting flows. There are at present no methods of describing the breakup of building contents. Thus, presently available methods are probably not good enough to adequately define debris distributions.

Similarly, we have tools (mathematical models) to predict the collapse and breakup of a wall (struck head-on, side-on, or rear-on), analyze the conversion of structural elements into debris and predict the debris translation/deposition. But these tools have never been verified in a realistic way. One weakness is a lack of understanding of how fragmentation occurs in a sufficient variety of wall types and overpressure levels. Also, experimental verification of the sequence of building wall

failures, as well as the debris translation model, is required, Structural debris, when it occurs, is likely to be superimposed on room-contents debris.

Building and Industrial Records Preservation

Of critical importance to postattack recovery are engineering and industrial building plans and documents. Currently, some industries have protected and duplicated sets of critical documents. It is not believed that government agencies, including cities and states, have either protected their building records or have duplicate records in hardened locations. A careful evaluation is needed to determine which government and industrial records are of critical importance to postattack recovery and policy should be established on the steps to be taken to protect these records in case of attack.

Multiburst Effects/Response

Before rational research topics can be recommended, probably attack conditions producing multiple bursts should be defined in terms of a mix of weapon sizes, time intervals between bursts, and area covered.

A given target (shelter), strengthened against relatively low overpressure, could easily be hit by two blast waves if its location is between two aiming points, or among several amining points at various distances. Another source of multiburst effects on a shelter comes from a mix of delivery systems (land-, air-, and sea-based, for example), having a unique delivery time, and its own probabilities of arrival as well as its own CEPs.

A check of IITRI files to see if any structures-related work has been published on multipleburst effects revealed only one small report published by the Rand Corporation (March 3, 1961), "Structures Under Repeated Blast Loadings" by Paul Weidlinger. The report is interesting, but limited to structures that can be represented by single-degree-of-freedom systems having elasto-plastic resistance functions. Also, it

assumes that the time interval between blasts is larger than the duration of the blast pressure and larger than the elasto-plastic response time of the structure. A number of other assumptions limit the class of structures to which the analysis applies, though not much more than the assumptions stated here. The author concludes that structures designed to resist a larger number of blasts, provided that the peak intensity of each blast is somewhat less than the design assumption for a single blast. (The blast intensity of a small number of repeated shots need not be much smaller than the intensity of a single destructive blast to permit the survival of the structure.)

This conclusion seems to apply to blast-resistant structures much more than to conventional structures. Obviously, the case when the time between bursts is less than the duration of the blast pressure presents a more difficult problem and one that should be considered. It is worth noting that, if the weapons should be radiation intense, the structure may survive a series of bursts, but the occupants will be casualties because of multiple doses of nuclear radiation.

Should multipleburst effects be considered, then the need is to define the hazard environment in much more detail than has been done thus far. When this has been done, work should then concentrate on casualty estimation, structural response and fire spread.

Upgrading of Existing Structures (Key-Worker Shelters)

In the process of upgrading existing structures for either key-worker shelters in the 30 to 50-psi range or for host area shelters in the over-pressure region of less than 3 psi, the basic structural response of the shelter can be significantly improved. Whereas the structural response may be predicted accurately for the non-upgraded structure in many cases, this cannot be done for the upgraded structure. To upgrade to the 30- to 50-psi range, it is necessary to select a floor system that is initially strong. For this reason, reinforced concrete (R/C) slabs are chosen for upgrading, which complicates the problem since upgraded R/C slabs are the most difficult for accurate response predictions. This results

because the reinforcing steel is not located where it can be effectively utilized by the upgrading, i.e., post supports have been placed at the midspan of a beam causing a negative moment in a location where there is only positive-moment steel. Presently, a manual is being prepared recommending upgrading systems for a variety of floor systems. Some of the methods in the manual have been verified through test. The remainder should be verified to develop reliable techniques for design and analysis of upgraded floors. To provide data for people survivability, the tests should be carried to collapse.

Two other significant structual problems with upgraded key-worker shelters are the response of the basement walls to the blast-induced soil loadings and the effect that the aboveground structure has on the basement shelter. There are no data available on the loading and response (beyond minor cracking) of basement walls at the 30- to 50-psi range. The house basement walls in early nuclear tests (1953 and 1955) did not fail, but they were located at low overpressure levels. The problem is complicated since it involves dynamic loading, soil/structure interaction and support at the wall top by a floor slab that may also be near failure.

Previous work on basement shelters has assumed that the aboveground structure collapses without affecting the shelter. In reality, there may be large columns that are continuous into the basement. The failure of these columns may also fail the basement roof slab, destroying the shelter. Both of these problems need to be investigated analytically and through tests.

With shelters in the 30- to 50-range, many problems become more intense, such as the debris that may block shelter exits, closures that need to be designed for and tested at the high overpressure level, ventilation systems, and fire outside the shelter. These areas, some of which have been mentioned elsewhere in this report, need to be looked at in detail at the 30- to 50-psi range.

Host area shelters may need structural strengthening in order to support the soil cover necessary for radiation protection and carry the less-than-3-psi blast loads expected in some host areas. The structural

response of these shelters will also be altered, requiring in some instances verification tests of the upgrading.

Casualty Estimation (People Survival)

A casualty/survivability function for a given shelter relates the probability of people survival within the shelter for a range of weapon environments referenced to free-field overpressure at the location of the shelter.

Figure VI-3 shows the probability of people survival against three casualty mechanisms, debris, primary blast, and nuclear radiation. Curves are shown for each of the three casualty mechanisms (effects) and for combined probability of survival against all three is determined as a product of the individual effects probabilities of survival, thus

$$P_s = P_{pb} P_d P_{ir}$$

where P_s = the combined effects probability of survival

P_{pb} = probability against primary blast

P_d = probability against debris

P_{ir} = probability against radiation

For a given shelter, the design overpressure appears to be a good indicator of the probability of survival at that overpressure. However, this is not the case when the probability involves higher overpressure levels, other weapon yields, and effects other than blast. Therefore, what a given shelter is good for without its casualty function is really not known. Casualty functions have the following uses:

- They describe the protective capabilities of personnel shelters for the relevent range of weapon environments, i.e., from the weapon environment at which the probability of survival is 1.0 to that where the probability is zero.
- They provide the means for comparing the relative effectiveness of different shelters and, therefore, selecting the most effective shelters for a given need.
- They provide the means for comparing different shelter systems and selecting the most effective shelter mix.
- They are useful for damage-limiting studies.

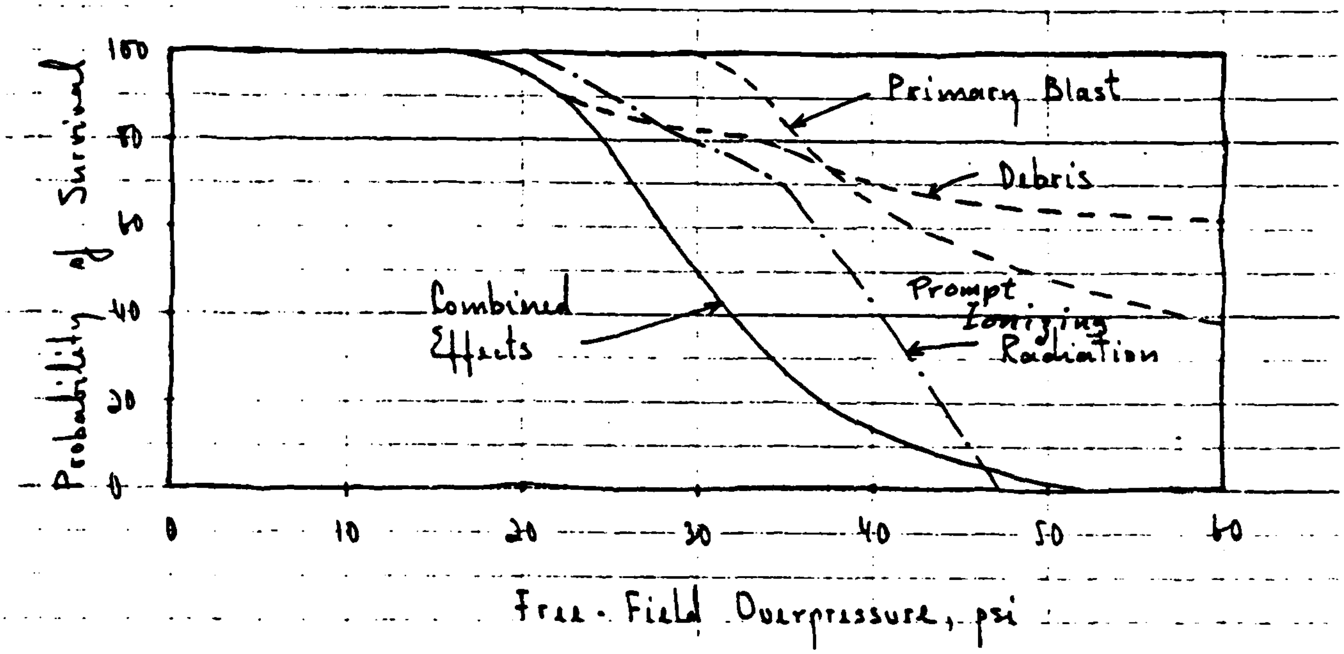

Fig. VI.3 Casualty Function for a Shelter

Since casualty functions for shelters and shelter systems are central to the development of an effective emergency preparedness (civil defense) system for the civilian population, it is important that casualty function methodology be developed on a firm basis. The following tasks are recommended:

- Formulate a casualty function methodology to include the effects of blast, debris, initial and residual nuclear radiation, toxic gases produced by fires, and flame and heat exposure.
- Develop casualty functions for all reasonable shelter concepts to include:
- \- Key-worker shelters
- \- Industrial shelters
- \- Host area shelters.

Field Testing (HE)

The blast/structures tests proposed by FEMA for inclusion in the August 1981 DNA 600-ton High Explosive Test, MILL RACE, were discussed by Workshop 2 participants.

Modified versions of the Key Worker Shelter Test and the Host Area Shelter Test proposed by SSI were recommended for inclusion. The FEMA Key Worker Expedient Shelter Test was also recommended but at lower priority, and only after design analysis and suitable shelter and experiment design changes are made. A supplementary shelter fire survival experiment using the lumber version of the FEMA small-pole expedient shelter after the blast testing at MILL RACE was also suggested. The WES-proposed waffle slab experiment was not recommended for inclusion.

An austere version of the experiment proposed by SRI on Responses of Structures and Debris Translation was endorsed by the workshop.

Industrial hardening proposals were discussed, but no conclusions were reached.

Tests relating to the following topics were also recommended for possible inclusion:

Debris protectors for equipment
Wood joist floor collapse
Idealized debris distribution
Responding standard floor
Responding basement walls
Closures
Furniture breakup and movement.

SCOPELET

Analyze City Complex (Crude Cut)

When an urban complex is attacked by a nuclear weapon, the structures involved in the blast are damaged to varying degrees. This damage in all cases results in the formation of debris that is various-sized and, depending upon the blast flow field at any given point, may be translated considerable distances from its original location. This debris results in a nonuniform overall field that will greatly differ from point-to-point around the detonation point, depending upon the original construction type and use (e.g., industrial, residential, high-rise) and upon overpressures. The nature and character of this debris field will greatly impact the initial fire distribution, the subsequent growth, and the threat to critical facilities and shelters, and they will greatly influence postattack countermeasures in firefighting. Without at a minimum a crude understanding and characterization of a typical, single-burst urban debris field, it is not possible to fully determine the scope of or identify critical parameters for initial fire growth, firespread or countermeasures.

This task will make a first cut at developing structural damage and debris contours to approximate roughly the debris distributions within a "typical targeted city." This will provide a major data set for fire researchers that can be used to identify critical parameters before going forward with other efforts.

The task will be accomplished by breaking up the selected city into gross areas of similar building types, then assuming a single-burst attack with a large yield weapon at some point in the city. Structural damage will then be generally characterized in the building-type areas as a function of overpressure. For each area, debris fields will be developed

and a gross overall debris field put together. This field will be characterized from GZ out to the no-damage range. This initial cut is considered to be a hand labor effort that uses back-of-the-envelope computational techniques and mainly identifies gross features of the debris field. Prior to initiation of the actual debris computations, it will be necessary to carefully interface with fire researchers concerned with initial fires, firespread and fire countermeasures.

SCOPELET

Key Worker Shelter Studies

From 3 to 6% of the population is expected to be required to remain in high risk areas and will require shelter for protection from all effects of a nuclear weapon at the 30- to 50-psi over-pressure range. Presently, manuals are being prepared that contain recommended procedures for upgrading basement areas in existing structures to provide shelters for these key workers. To insure that the shelters perform as required, all structural aspects of the shelter need to be analyzed thoroughly and tested to failure, which will provide verification of the design and analysis of the upgraded system, as well as data for people suvivability analysis. The studies of greatest concern structurally are:

- Test of upgraded systems to verify design and analysis
- Survey of existing data to determine most common basement wall types
- Analysis and test of basement walls
- Analysis and test of closures of all types expected to be used in the shelters.

SCOPELET

Debris Formation, Translation and Interaction

Airblast affects fire ignition, development, and spread through two mechanisms: first, the blast creates an air flow field that changes the microscopic balance of energy and reactants at the actual or potential fire site; second, the blast may drastically alter the exposure of combustible material to both primary and secondary ignition. At high overpressures (e.g., 50 psi), the blast may remove walls and other shields while thermal irradiation from the fireball is still underway. At both high and low overpressures, blast may transform structural elements and contents into debris and create a mix of combustible and noncombustible materials drastically different in potential for fire growth and spread from that irradiated before blast arrival. Clearly any evaluation of the fire threat to a specific environment must begin after, rather than before, debris formation and translation have been taken into account.

It is the objective of the proposed research to establish a means, employing both experiment and calculation, for describing the features of an urban debris field that are important to fire ignition, growth, and spread. It is recommended that the work be regarded as consisting of four phases: (1) outside wall breakup and distribution; (2) distribution of interior contents; (3) interior partitions breakup and distribution; and, (4) interaction of debris elements to produce a final pattern. Although the treatment of each phase in complete isolation from the other phases is not intended, work should generally proceed from Phase 1 to 4. At the end of each phase at least a modest effort

should be made to evaluate the influence of the findings on fire ignition, growth, and spread. At the conclusion of the program there must be a major effort to incorporate the findings in an evaluation of debris effects on fire.

Phase 1 is presently underway with a theoretical treatment of the production of outside wall debris from a four-sided, load-bearing masonry structure, confirmed in part by incomplete reports of the final locations of wall debris after blast impact at PRAIRIE FLAT. Further experimental investigation of four-sided, load-bearing structures with complete instrumentation (including camera observation) is needed, as well as both theoretical and experimental study of other urban construction types, such as steel and reinforced concrete frames.

Phase 2 also has begun with experimental work at URS and BRL. Generalizations consistent with these results should be sought. Few experimental results of Phase 3 exist, but a beginning was made at URS which must be extended by more realistic tests, accompanied by attempts to generalize.

Phase 4, at present virtually virgin territory, is most important in any attempt to describe fire in an urban complex. Experimental observations of blast pressures in model complexes are available, and a modest beginning has been made in describing wall collapse resulting from these disturbed blast fields, but an attempt to describe debris distribution should properly await development of confidence in methodology growing out of earlier phases in the program.

SCOPELET

Modifications of Blast Wave Characteristics in Urban Areas

The presence of structures in urban areas severely disturbs blast waves passing through the area. This phenomenon can have important consequences for a number of blast and blast-fire problems. Some are described below.

Structural Response--Current response models and analyses generally utilize a sharp fronted blast wave as the forcing function. In many urban areas, nearby structures in essence degrade the blast wave front to one that has a relatively slow rise, a lower peak pressure, and a very greatly reduced impulse. All of these can modify structural response significantly.

Debris translation--Substantial changes in dynamic pressures (due to multiple reflections) can essentially eliminate directed flow, severely influencing debris translation.

Blast-Fire Interaction--Large changes in flow within rooms can occur, altering any tendency for flow within rooms (caused by the blast wave) to blow out fires.

Information currently available on these "shielding" phenomena is fragmentary. It includes: shock wave studies of individual blocks and multiple blocks (of various geometries); small-scale high explosive tests using city complex models (with regular and uniform obstacles); and, from tests with 1000-lb high explosive charges, some recent information on single model houses and a limited complex of nine model houses. Overpressure measurements were made, but dynamic pressure measurements

were not. Dynamic pressure "shielding" results were obtained by BRL from 2-D geometry, shocktube tests. These are suggestive but incomplete.

There has been no attempt to approach the problem theoretically (it is a difficult problem even with regular obstacles).

Research on this problem should have a series of objectives, some of which are:

- Review and analyze information currently available to provide the blast and blast-fire community with <u>some</u> idea of the possible effects of urban area irregularities.
- Adapt two-dimensional codes to provide some information.
- Analyze information currently available with the objective of designing a combined experimental-theoretical (analytical) program that will provide necessary answers.
- Undertake designated research (both experimental and theoretical).
- Perform a sensitivity analysis to determine the relative importance of urban area differences.
- Develop a computer model(s) of the interaction phenomena. Initially the model would probably provide crude estimates, but refinement should be incorporated to the extent that actual urban area irregularities allow.

Casualty Estimation (Personnel Survival)

Definition

Casualty/survivability studies are done to assess damage and to compare the relative effectiveness of alternative shelter systems. Such studies can be performed effectively only when each shelter in the system is described by means of a casualty/survivability function. A casualty/survivability function for a given personnel shelter relates the probability of people survival for a range of hazard environments.

A typical survivability function is shown in Figure VI-4. This function is for people located on the first floor of a framed building with masonry curtain walls and very few windows. Superimposed on it is a casualty function (shown by a dash line), which is its complement, i.e.,

$$P_c = 1 - P_s \tag{1}$$

where P_c is the probability of casualty and P_s, the probability of survival.

For convenience, the functions of Figure VI-4 are related to the free-field overpressure at the site of the shelter.

The functions shown in Figure VI-4 are for combined effects. Individual effects on which they are based are shown in Figure VI-5* and include debris from the break-up of the masonry curtain walls, tumbling and impact of individuals after the walls are breached by the blast, and ionizing radiation. Combined effects probability of survival at a given overpressure level is obtained on the basis of individual effects probabilities as follows.

$$P_s = P_d \, P_{bt} \, P_{ir} \tag{2}$$

*Figure VI-5 debris curve beyond 12 psi rises because increasing blast velocities carry more light debris above prone shelterees and move shelterees ahead of and beyond heavy debris.

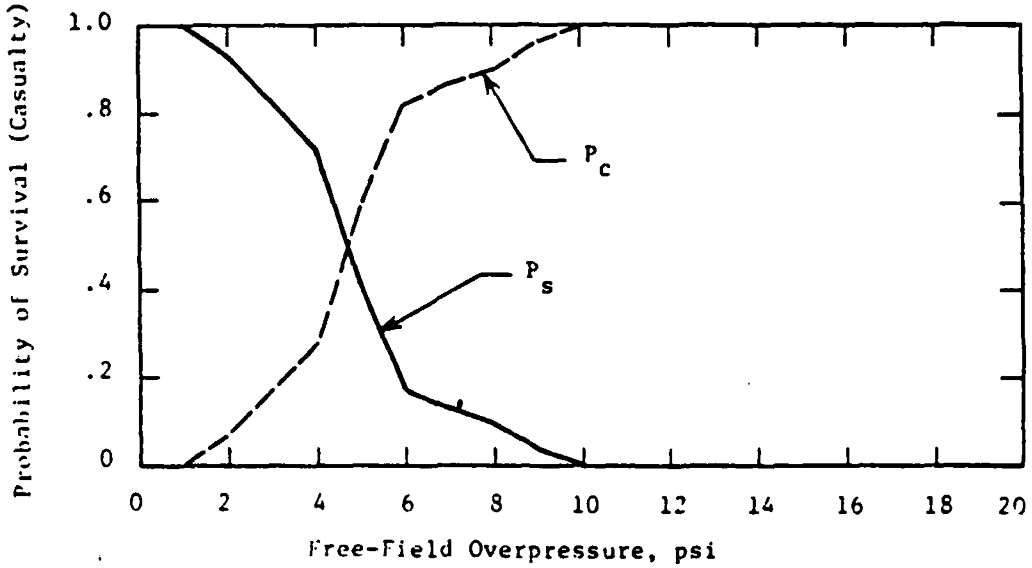

Figure VI-4 People Survivability Estimate (Combined Effects)

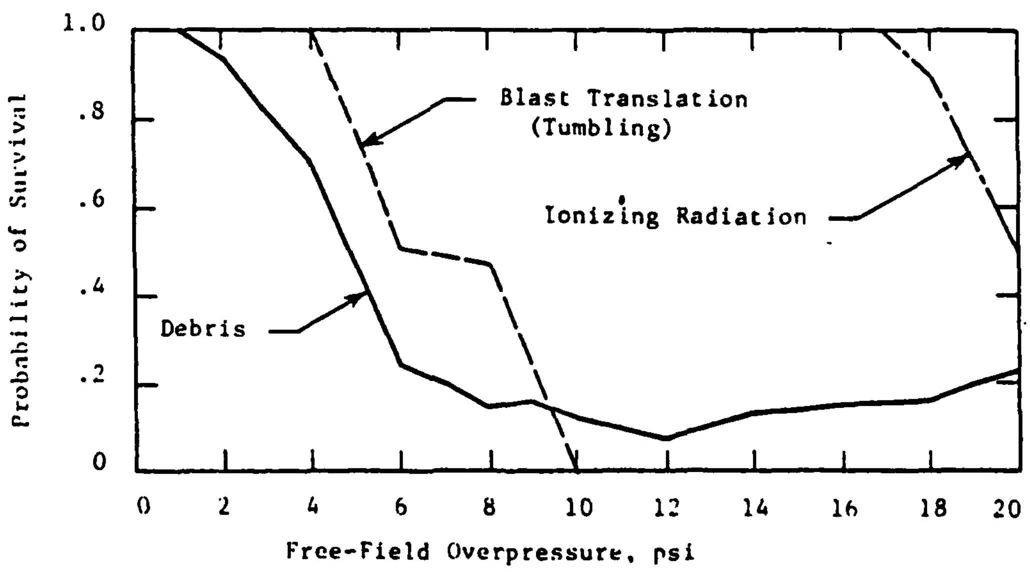

Figure VI-5 People Survivability Estimate (Individual Effects)

where P_d, P_{bt}, and P_{ir} are probabilities of survival against debris, blast translation and ionizing radiation, respectively. This is valid because the individual effects are independent.

Current Need

As the present time our catalog of casualty functions is limited. A rational methodology for developing casualty functions on a probabilistic basis was formulated over the past year. However, as yet it has not been applied toward the development of casualty functions.

There is a need to identify a series of personnel shelters for host and risk areas. This should include expediently upgraded basements for high (greater than 30 psi) and low (less than 3 psi) overpressures, and hard, expedient (single purpose) shelters of types tested by Oak Ridge. A catalog of such shelter concepts should be developed to cover the entire spectrum of sheltering needs. Each of these shelter concepts should be analyzed and a casualty function should be assigned to it.

Recommendations

It is recommended that studies be initiated to develop casualty functions for likely personnel shelters in both host and risk areas.

A number of personnel shelter concepts and expedient upgrading concepts for basements have been produced over the past several years. In addition, there exists the expedient shelter handbook developed by Oak Ridge. An initial "casualty estimation" study should consider a representative mix of shelters in three categories:

Expediently upgraded shelters for host areas
Expediently upgraded shelters for risk areas
Expedient, hard personnel shelters

Approximately twelve shelters in each category should be considered in the initial study.

SCOPELET

Frame Response of Shelters for Key Workers

Most key-worker shelters will probably be in upgraded basements. Not only should the strength of the basement area and the upgrading method be carefully studied, but also the effect of the response and collapse of the rest of the building upon the safety of the shelter. A blast wave would not necessarily shear a building off cleanly just above the basement. Leaks and other localized failures could be caused by the response of the frame above the ground. This problem needs to be examined first theoretically and then verified through model or full-scale tests.

WORKSHOP 3: FIRE SPREAD AND THREAT

This workshop 3* looked at the problem of the vulnerability of critical facilities and key people during a mass fire. The principal effects of a mass fire are to change the air temperature, thermal radiation level, air velocity, relative humidity, and the chemical composition of the environment to which the facilities and/or people are exposed. Building collapse, firebrands and other flying debris, as well as explosions and flooding due to the rupture of gas and water mains during the growth of the mass fire, could provide additional, less predictable hazards. To determine the particular people and facilities that are at risk if they are involved in a mass fire and the amount and type of extra protection required, it is necessary (1) to specify the requirements of their environment which must be met for their survival and then (2) to determine the local environment which would be created by the mass fire. If the critical facilities or key people are located inside enclosures that would serve as shelters, it would be necessary to determine the extent to which those structures would alter the effect of the mass fire environment. To determine whether and when particular facilities and/or people will be involved in a mass fire, it is necessary to know the weapon yield, the point of detonation, and the weather conditions as well as the distribution and type of buildings and other urban fuels. This information is needed to find the initial distribution of burning buildings after the thermal pulse is over and the blast wave has passed (this information is in the province of Workshop 1) and to predict the fire spread as a function of time through the urban area, given the debris field provided by Workshop 2. The necessary research has been divided into three tasks.

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*Members of Workshop 3 were: R. S. Alger, C. P. Butler, T. Goodale, K. Kaplan, W. J. Parker, Chairman, R. Small, R. C. Sparling, and T. Waterman.

Task 1: Mass Fire Environment

The function of this task is to develop a general mass fire model which will predict the fire environment in a large section of an urban area, assuming that a given area is involved and a given fraction of the combustible structures are burning. The complexity involved in urban fire spread would thus be avoided and the maximum threat assumed. The model would use the area and distributed heat-release rate per unit area as input data and predict the air velocity, the oxygen and carbon monoxide concentrations, the temperature, and the thermal radiation level. The spatial resolution of the input and output would be of the order of a kilometer. A target-specific model with much finer spatial resolution should be developed to determine the modifications of the environment which might occur in the neighborhood of a critical facility because of local differences in fuel loading. The predicted environment would be used to calculate the fire-induced conditions inside a shelter or other enclosure that may be housing key people or critical resources. The history of the external environment would also determine when escape from the shelter is possible.

The literature pertaining to the microscopic physics of large-area fires should be reviewed and analyzed, so that areas where current understanding is deficient can be identified. Features specific to a nuclear-weapon-initiated city fire should be considered in detail. Specifically, the mass fire models developed for OCD and DASA during the 1960s and 1970s should be throughly reviewed, as well as later work in this area. Based on hydrodynamic and thermodynamic principles, a self-consistent physical model should be constructed which accounts for the unique properties of large-area fires. Due to the scale of such events, a significant perturbation of the atmosphere is expected to result and a recirculation flow field may be established which could account for the high-velocity winds characteristic of the fire storms observed in World War II fire bombings. Preliminary development of the governing equations for a mass fire shows that the urban area interactions may be principally inviscid.

Suitable scaling relationships should be sought which would permit the use of small-scale experiments to verify the physical concepts involved. Again, the scaling relationships developed by Corlett, Williams, and Long in the 1960s for mass fires should be reviewed.*

The required input data on burning rates will be estimated, based on past experiments on the burning rates of individual buildings and debris piles. The rate of oxygen consumption can be estimated from the burning rate, but it will be necessary to obtain data on the rate of CO production from burning buildings. The ranges at which the buildings remain intact, damaged, or collapsed will have to be obtained from Workshop 2 for typical yields. In addition to its effect on the burning rates of the buildings, the effect of the collapse will be to provide a burning debris pile, which could cause a much larger thermal threat to an underground shelter if it is not properly located.

Approximately 1 man-year per year for 3 years would be required to develop the general mass fire model and the target-specific model.

<u>Task 2: Fire Spread Model</u>

While Task 1 deals with a fully developed mass fire which is assumed to envelop the critical resource whose external environment is to be determined, Task 2 is concerned with predicting the actual area covered by the mass fire at any time and thus would determine which critical resources are at risk. The general fire spread model would require information from Workshop 1 on the buildings which are on fire as a direct result of the blast and thermal pulse and on the state of the damage to the buildings from Workshop 2. By the mechanism of radiation, firebrands and contiguous spread, the area of the city involved in fire will grow with time. The general ideas of the model, constructed by the previous members of Workshop 3, are shown in the report of the Proceedings of the

*The editors suggest reviewing also the proceedings of the Mass Fire Symposium held under TTCP sponsorship in Canberra, Australia (February 1969).

1979 conference (Figure VII-I, page 79). They visualized the model to be a main program that would manage the entire calculation sequence and modulate the interaction of submodels to achieve a maximum degree of decoupling, in the sense that changes to any one submodel would preferably propagate only into the main program. Coupled to the main program would be a set of functional subprograms.

The main program was visualized as containing four major elements, or subtasks, although only the first three, listed here, are specific to the fire-growth model:

Subtask 1: Input Module--This element would accept city survey data, in a form that would be convenient to the survey process, and translate it into the fire parameters required by the rest of the program. Presumably, the input module would be sensitive to any new data demands occasioned by the substitution of one submodule for another. The output of the input module would be a city descriptor library.

Subtask 2: Initialization Section--This element would call a number of submodels based on the results from Workshops 1 and 2 to reconfigure the city as a result of the nuclear attack, i.e., modify the descriptor library. Specific submodels would consider:

- Thermal radiation
- Blast effects
- Debris generation
- Weather

An additional output of this initialization section would be the number and distribution of sustained ignitions. In summary, this section would provide the time-dependent calculation with initial conditions:

- Fuel bed descriptors corrected for blast damage
- Distribution of initial fires

Subtask 3: The Fire Growth and Spread Predictor Proper This section, in turn, would have two subsections: an elliptic section, which would consider the fire at a particular instant, and a hyperbolic section, which would allow for growth time. The elliptic section would consider the fire intensity, toxic gas (CO) production, the fire plume(s) radiation field, induced micrometerology and brand throw, all in an interactive sense--i.e., these are tightly coupled effects. The hyperbolic section would test for changes in the overall fire size due to:

- Burnout
- New ignitions due to firebrands
- New ignitions due to radiation
- Contiguous spread

This section would also test for changes in intensity of the existing fire and in the size and intensity of the incremental fire. Note that time increments could be fixed or implicit.

The time for the development and spread of the mass fire will also depend on the time between the ignition of the building or its contents and the complete fire envolvement of the building. Mathematical modeling efforts such is that in the Center for Fire Research at NBS are addressing this problem so that FEMA support is not needed in this area.

Because of the uncertainty of the yield and the point of burst, the initial conditions are generally not known. Also, the complexities involved in the fire spread from building to building without readily available means for experimental verification give the predictions a high degree of uncertainty. Since the maximum protection required for an initial resource can be determined from the mass fire model developed in Subtask 1 and because support for the fire spread model may be available from DNA, since they are in a position to specify the yield and the point

of detonation,* Subtask 2 is given a low priority at this time. It is anticipated that 1 man-year per year for 5 years would be required for this project.

Task 3: Vulnerability

This task would formulate a list of vital facilities such as that given in the report of the 1979 Conference (Enclosure 2, page E17), and would establish the criteria which must be met by the environment in which these facilities and key people might be located. Only the environmental parameters affected by the fire, such as air temperature, thermal radiation, oxygen and carbon monoxide concentrations, and relative humidity, are considered. If these facilities are normally exposed, the difference between the criteria and the environment predicted by the mass fire model developed in Task 1 will determine the amount of protection that will be required. If the facility is located in an enclosure, the interior environment will be calculated from the mass fire environment combined with the details of the enclosure, such as its thermal resistance and ventilation system. As an example, three classes of shelters might be identified which would provide different levels of protection, depending on the sensitivity of the facility or people. Here the term "shelter" may mean the enclosure in which the facility or people are normally located, as well as a structure built or modified for protection against the nuclear threat. Table VI-3, which indicates the sensitivity of the people or facilities to the environment, illustrates the approach.

*The editors assume what is meant here is that DNA has unique responsibilities, such as providing guidance to strategic targeting planners, for which specific-scenario damage assessments have more pertinence than they do in the emergency management applications of FEMA.

Table VI-3

MODEL FOR DETERMINING VULNERABILITY

Shelter Class	Vital Facilities	Temperature	Relative Humidity	Gas Concentration
I	People	Severe	Moderate	Severe
I	Electronics	Severe	Severe	Moderate
I	Medical Supplies	Severe	N.A.	N.A.
II	Fuel	Moderate	N.A.	N.A.
II	Food	Moderate	N.A.	N.A.
III	Clothes	Light	Light	N.A.
III	Water	Light	N.A.	N.A.
III	Machinery	Light	Light	N.A.

The criteria will actually be given in terms of degrees celsius, percent relative humidity, and gas concentrations in percent for oxygen, and for carbon monoxide and other toxic gases. It is assumed that other threats, such as blast and the electromagnetic pulse, are being covered elsewhere. Also, potential health hazards in personel shelters, other than hazards imposed by the fire, are not considered here.

A survey would be made of existing structures which now house these vital facilities, or to which these facilities might be moved, to determine their adequacy to provide the type or protection indicated by the above analysis. These structures would also be evaluated with respect to their ability to withstand the fire. Recommendations would then be made as to the need for upgrading the present structures or moving the critical facilities and key people into suitable shelters.

It is not the purpose of this project to identify the facilities and personnel which would actually be labeled critical,* but to provide FEMA

*Editor's note: This is one of the policy matters we previously referred to in our footnote on page VI-22 of the summary of Workshop I.

with crucial data which, combined with many other factors, would permit them to make that decision and determine the additional protection or countermeasures required. The range of facilities and shelters examined on this project should be broad enough to cover all possible choices that might be made by FEMA. It is anticipated that 2 man-years over a period of one year would be required to complete this project. Table VI-4 shows the program recommended for the next two fiscal years.

Table VI-4

PROGRAM RECOMMENDED FOR FY 1981 AND 1982

Year	Project	Level of Requested Support (K$) High	Intermediate	Low
FY81	Mass fire environment (general mass fire model)	120	100	80
FY81	Vulnerability criteria	200	180	150
FY82	Mass fire environment (target specific model)	120	100	80
FY82	Urban fire spread model	120	100	80

WORKSHOP 4: COUNTERMEASURES TO PROTECT CRITICAL FACILITIES FROM FIRE

The tasks given this year's Workshop 4 participants* were:

1. To consider key-people shelter criteria from the standpoint of locations, size, habitability, and stay time.
2. To review FY80 requirements and formulate a program for FY81 in view of no support to date.

With regard to the review of the 1979 workshop and FY80 research efforts, the 1979 workshop participants discussed some 13 research ideas:

Firefighting equipment and tactics (peactime)

Public awareness and mass education (peacetime)

City shelter (peacetime)

Key workers (peacetime)

RADEF (peacetime)

Increased readiness (crisis period)

Protective postures (survival period)

Life support (survival period)

People protection (survival period)

Emergency Operations Centers (peacetime)

Emergency Operations Centers (survival period)

Fire-caused relocation and rescue (survival period)

Equipment/shelter salvaging (postsurvival period)

All of these areas are vital, and the 1980 group tended to agree with the need for research in all of them. The 1979 group went on and identified seven initial research project recommendations, as follows:

Task 1: Site selection criteria for key-worker shelters.

Task 2: Should key equipment be relocated or protected in place?

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*Members of Workshop 4 were: M. Drake, J. Jacobs, R. K. Laurino, H. G. Ryland, V. Sjölin, and C. Wilton (Chairman).

Task 3: Optimization of firefighting equipment performance and tactical procedures to make best use of limited manpower and water resources during the survival period.

Task 4: In what other areas can computer simulation and decision analysis techniques be applied to fire countermeasures?

Task 5: What are the essential industries and who are the key workers?

Task 6: Prediction of firebrands in blast/fire interaction zones.

Task 7: Recovery of film showing blast/fire (e.g., DASIAC).

Upon completion of the 1980 workshop research agenda, four of the tasks were still considered high priority and included on the recommended research list: Task 1, key-worker shelter criteria; Task 2, protection/relocation of key equipment; Task 3, optimization of firefighting equipment and procedures; and Task 5, identification of key industry and workers. With regard to the other three, it was the opinion of the group that: Task 4, computer simulation and decision analysis, was necessary, but might be a little premature because of lack of data on essential industries, key workers, etc.; Task 6, production of firebrands, was probably not the responsibility of this group, and from discussion with other workshops it was determined that interest in this had waned over the past year or so; Task 7, recovery of blast/fire film, remained somewhat of a mystery, since no one could recall what particular film or films were to be recovered and who was going to use it.

A review of recent funding for research indicated that the original statement, "No support to date," was essentially correct, and none of these items has received direct support. It was noted, however, that certain elements of currently funded research, such as the FEMA-sponsored industry protection study, the key-worker shelter manual program being conducted by Scientific Service, Inc., and the DNA-sponsored critical industry studies being conducted by the Center for Planning and Research and SAI, Huntsville, would yield valuable data.

The results of Workshop 4's deliberations are summarized in the following displays, which are copies of the flip charts presented on the last day of the conference. These are followed by brief descriptions of each of the tasks, authored by the workshop participants.

1. CRITICAL INDUSTRY & ORGANIZATION SELECTION

(Guidelines for Local & Regional Planners)

TYPES

- CRP SUPPORT
- POST-ATTACK SUPPORT
- MILITARY SUPPORT

TASKS

- RESOURCE or PRODUCT SELECTION
  (Production level, conversion substitution)
- FACILITY or ORGANIZATION SELECTION
  (Location, hardening potential.)

2. CRITICAL INDUSTRY & ORGANIZATION PLANNING

(Guidelines for local planner & plant mgmt.)

TASKS

- DEVELOP SITE-SPECIFIC INDUSTRY PROTECTION PLAN.
  - ESSENTIAL PROCESS & EQUIPMENT SELECTION
  - ORGANIZATION & MANAGEMENT PLAN
  - MUTUAL AID PACTS

- KEY WORKER IDENTIFICATION PROCEDURE.
  - DEFINE ROLES
    - Peacetime
    - Crisis Period
    - Trans-attack
    - Immed. Post-attack

- SHELTER SELECTION PROCESS
  - SITE SELECTION
  - AVAILABLE / EXPEDIENT
  - NEW

3. DEVELOP SHELTER DESIGN CRITERIA

(Guidance for local planners & plant managers)

LOCATION

AT, OR NEAR, KEY FACILITIES

TASKS

- STRUCTURAL REQUIREMENTS (blast, thermal Radiation, fallout, fire, debris, escape)
- LIFE SUPPORT REQUIREMENTS (air, water, food, EMS)
- REQUIREMENTS FOR MONITORING EXTERNAL ENVIRONMENT
- COMMUNICATIONS REQUIREMENTS
  - TRANS-ATTACK
  - IMMEDIATE POST-ATTACK
- SHELTER STOCKING REQUIREMENTS
  - PEACETIME
  - CRISIS PERIOD
- GUIDELINES FOR TRADING-OFF SHELTER REQUIREMENTS.

4. CRITICAL INDUSTRY PROTECTION

(Local planner --- Plant management)

TASK

- DEVELOP PROTECTION PLAN FOR OPERATING PLANTS.

  (Peacetime, Crisis period, trans-attack, post-attack)

  - MANAGEMENT
  - ESSENTIAL PROCESSES/EQUIPMENT
  - KEY WORKER PROTECTION
  - EQUIPMENT/PROCESS MODIFICATION
  - TIME PHASED HARDENING PROCEDURE
  - PROTECTIVE HOUSEKEEPING PROCEDURES

    (shielding hazardous materials, critical records, etc.)
  - WARNING-COMMUNICATIONS
  - PRODUCT CONVERSION PROCEDURES
  - PLANT PROTECTION
  - OPERATING REQUIREMENTS

    (raw materials, trans., resources)

5. OPTIMAL USE OF EMERGENCY FORCES

(Guidance for local planners & organization mgrs.)

EMERGENCY FORCES

POLICE, FIRE, MEDICAL, etc.

TASKS

- REQUIREMENTS ON OPERATION CAPACITY FOR IMPORTANT GOALS
- LOCATION OF EMERGENCY FORCES IN RELATION TO TASKS & PROTECTION—
  PERSONNEL & EQUIPMENT
- SURVIVABILITY, CAPACITY, & DURABILITY OF FORCES
- OPERATIONAL PROCEDURES FOR THE CRISIS, TRANS-ATTACK & IMMEDIATE POST-ATTACK PERIODS

6. CRITICAL RECORD PROTECTION

TASKS

- RECORD SELECTION PROCEDURES
  - PRIVATE (Industrial processes, equipment specifications, etc.)
  - GOVERNMENT (information for emergency services, property, ownership, etc.)
  - HISTORIC
- RECORD PROTECTION TECHNIQUES
  - STORAGE REQUIREMENTS
  - CONVERSION (smaller volume, more survivable, etc.)
  - PRESERVATION
  - RECOVERY (retrieval requirements)

Task 1 Critical Industry and Organization Selection

Background

The requirements for types and quantities of production are ultimately a function of national objectives. In broad terms, requirements can be categorized as:

- Support for crisis relocation
- Preparation for post-attack recovery
- Support of current or future military activities

CR support places the lowest demands upon the industrial system since it would require only subsistence of the population in the relocated posture (food, energy, government services, etc.). Post-attack and military support place increasing demands upon the industrial system and would require a greater variety and higher level of production.

In order to provide for the protection of key workers and essential facilities, it is necessary to estimate the types and levels of production and determine the characteristics of the industrial facilities likely to be selected.

Tasks

An initial task in addressing these issues would be resource or product selection. For this purpose, a range of possible demands should be determined based upon the alternative national objectives. Using established interindustry relationships, the type and quantity of production of various items and services should be estimated at the national and regional levels. Possible means of reducing the amount of risk-area production should be examined including substitution of products, expanded

use of non-risk-area production, and the use of inventories. By these means, the residual requirement for risk-area production should be estimated.

Given the estimated requirements for risk-area production, another important research issue would be essential <u>facility</u> or <u>organization selection</u>. The slack created by controlling demands would generally mean that only a fraction of the production capacity in risk areas need be selected for operation during crisis relocation. Criteria would thus have to be developed that permitted selection of specific organizations or facilities. Questions requiring examination include deciding which organizations would be capable of doing the planning required for CR operations (i.e., probably the larger organizations). Some consideration should also be given to the product mix of each facility and the feasibility and costs associated with emergency production. Another consideration would be the feasibility of supplying supporting services to a facility and the adequacy of inventories. From the attack preparedness point of view, consideration should be given to the feasibility of hardening the facility, and the possibilities and costs of supplying blast shelter for key workers.

Task 2
CRITICAL INDUSTRY AND ORGANIZATION PLANNING

The protection of critical industries is an essential element of any civil or national defense plan. Such industries will be required to support the military with food, ammunition, and other necessary supplies and also to support the civilian population with food, energy, communications, and other survival needs.

There are a number of research programs underway in support of the concept of Crisis Relocaion planning and critical industry protection in particular. One of the most relevant of these programs is one being conducted by Scientific Service, Inc. (SSI) to develop and Industrial Hardening Handbook. This handbook presents a generalized procedure for self-help industrial protection from both natural and nuclear disasters.

Any plan or handbook is useless, however, if it is not implemented, and currently industry is reluctant to invest the time and effort in planning and preparation for such a remote (in their minds) disaster as a nuclear attack. There is some interest in preparation for certain natural disasters (earthquakes, hurricanes, etc.), but this is only in specific regions of the country and only by very few industries in these regions.

What is required to make industry protective planning viable is:

1. A commitment at the highest level in the Federal government to civil defense in general and industry protection in particular.

2. Preparation of the material supplied to industry in a format that is acceptable, easily understood, and concise.

3. Initiation of a sales promotion campaign to the highest levels of industry management to: (a) make them aware of the program and (b) sell them on the benefits of the program.

4. Initiation by the Federal and state governments of a program of tax incentives or other benefits to industry for participation in the program.

Once industry is interested and understands not only the problems, but also the benefits that could be provided by a viable industry plan, the following tasks should be undertaken:

- o Development of site-specific plans
- o Identification of key workers
- o Selection of shelters

Development of Site-Specific Plans

As noted earlier, a generalized plan is being developed. This work is being supplemented by field and laboratory test programs, industry demonstrations, and other activities. As these data become available it is necessary for each critical facility to develop a site-specific industry protection plan. Such a plan should include: determining what equipment or processes are absolutely essential to continued production of critical items and, thus, must be protected; an organization and management plan for accomplishing the many hardening activities — evacuation of non-essential personnel, protection of vital records, etc.; and developing mutual aid pacts for sharing of resources and equipment in time of emergency. The specific ingredients of such a plan are shown in Figure VI-6.

Key Worker Identification

One of the more important elements of the plan is the selection of those members of the organization who are essential to the protection and operation of the facility and who will be required to remain behind. Their roles need to be defined for all phases of the crisis — peacetime, crisis period, trans-attack, and immediate post-attack.

One implicit element is the need for plans for evacuation and protection of the key workers' families. Without a viable plan for this, it is highly likely there will be no key workers.

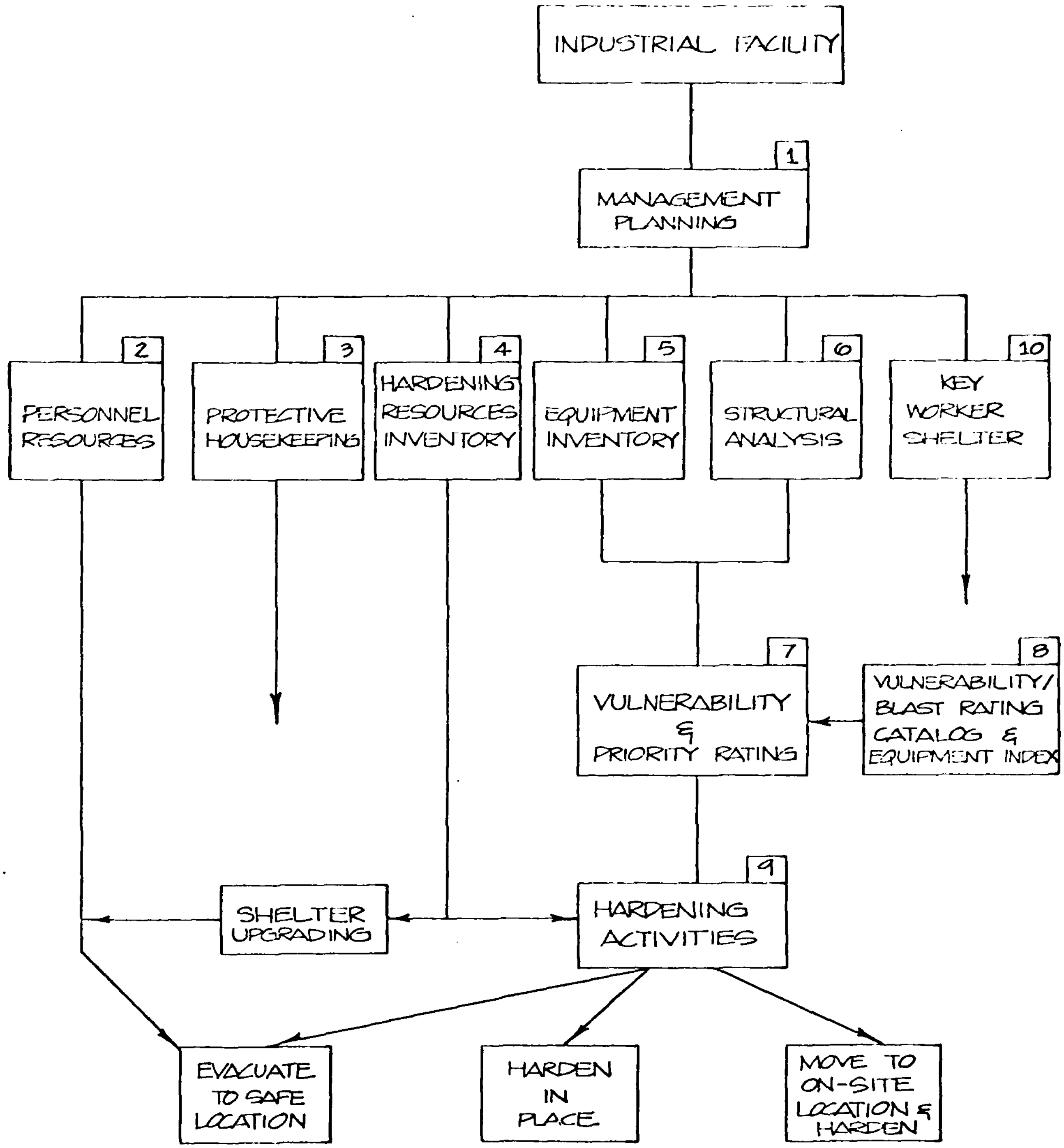


Figure VI-6 Flow Chart of Industrial Hardening Plan.

Shelter Selection Process

As part of the protection process it will be necessary to provide shelter for the identified key workers. As part of the planning process it will be necessary to identify shelters, either within the facility or in close proximity. These may be either structures or expedient shelters constructed during the crisis period, or dedicated shelters constructed separately or as part of remodeling or new construction.

Task 3
DEVELOPING SHELTER DESIGN CRITERIA

Provision of shelter for the key personnel of critical organizations is generally recognized as an absolute requirement. However, little research has been done that would lead to guidance for local government planners or industrial plant managers in development of adequate key worker shelter. Indeed, even the question of location of such shelter, at the key facility, versus in suburban areas of lesser risk, is a controversial issue in need of study.

Several specific actions are recommended with regard to development of criteria for key worker shelter design, as follows:

a) Structural requirements should be identified taking into consideration the level of prompt effects risk of proposed shelter location. Requirements should be established for blast, thermal, and initial radiation hardness, for fallout and fire protection, and for entrapment mitigation.

b) Requirements and guidelines for life support systems should be developed, including standards for air, water, food, and emergency medical service for the key personnel.

c) Requirements for monitoring the external environment from within key personnel shelters should be established, along with guidelines for appropriate countermeasure actions based upon that measured environment.

d) Requirements for sheltered key personnel communications capability should be established, addressing the questions whom they must be able to communicate with, and how, during both the trans-attack and the immediate post-attack periods.

e) Shelter stocking guidelines should be developed for key personnel shelters. Some items must be acquired in peacetime if they are to be available at all, whereas other stocks might best be gathered only in a crisis buildup period.

f) The aforementioned requirements for key personnel shelters would necessarily produce conflict. The location of shelter relative to perceived risk impinges greatly upon structural and life support requirements. Good communications capability may lessen the requirements for monitoring the external environment with instrumentation. Research is needed to consider all of the specific actions discussed earlier, in order to develop guidelines for trading-off of shelter design criteria.

Task 4
CRITICAL INDUSTRY PROTECTION

Protection of critical industries is a subtask of the overall problem of ensuring that industrial production remains operational above a survival level. Development of self-help plans for industry to carry it through the crisis, attack, and recovery periods is the most practical alternative available to achieve this objective. Specifics of how to deal with critical industries through a crisis and attack period are unlikely to differ greatly from industrial hardening in general, but attitudes will have to change; a vital factor, therefore, will be marketing the concept to industrial management. To be successful, the first step is to establish concept credibility.

Tasks

A prerequisite for marketing a self-help preparedness plan is the development and testing of all plan elements to ensure and to demonstrate credibility and coherence. Some program elements are held in common with program discussed in detail elsewhere; for example, the piece entitled "Developing Shelter Design Criteria" discusses logistic support, communication, entrapment avoidance, etc., as well as structural requirements. These elements must be treated thoroughly and convincingly. In addition, specific elements not discussed under other topics that must also be addressed are:

- Advance management planning — priorities/decisions under crisis
- Selection of essential processes/equipment, in-plant
- Personnel resources, maintenance, and protection
- Alternative options (equipment/process modification)
- Time-phased hardening procedures (sequence and schedule)

- o Plant-site attack warning system and procedures
- o Key worker post-attack rescue/escape
- o Product conversion/substitution -- options/procedures
- o Attack period protection methods (alternatives/examples)
- o Operating requirements (materials, power, transportation, resources)

Advance planning is the keystone of preparedness, yet such planning will be unlikely so long as credibility for the entire concept is in question. At the industrial management level, where all plant action starts, credibility is in short supply. Virtually the entire military and economic might of the United States resides in U.S. industry, yet the industrial preparedness portion of an annual defense budget of over 150 billion dollars totals, perhaps, a million dollars. Industry management considers the credibility and concern indicated by economic commitment totally out of proportion to the magnitude and scope of the problem. They believe each of the items above represents a multimillion dollar effort to develop and to demonstrate convincingly. Such a development and demonstration effort involving many different types of industries will have to become a reality before industrial preparedness can be marketed successfully.

Task 5
OPTIMAL USE OF EMERGENCY FORCES

The protection of critical industries in turn requires the protection of people and facilities. People and facilities are protected by:

- o Passive components (e.g., site hardening)
- o Self help (e.g., actions that key workers can take to protect themselves, their equipment, etc.)
- o The community's emergency forces

For purposes of this discussion, the phrase "community emergency forces" is defined to include: fire protection, law enforcement, emergency medical, and debris removal services.

These services are obviously extremely important to the protection of critical industries, as well as the community in general. In fact, the effectiveness of these services may determine if attack-initiated fires are contained in the primary ignition area or spread throughout the community.

However, most community emergency services are not currently prepared to effectively perform these services within a post-attack environment. For example,

- o Public safety agencies do not have specific operational goals, objectives, and procedures for the crisis, trans-attack, and immediate post-attack periods. For example, they do not know which facilities to protect first, second, etc.
- o Public safety personnel do not know how to protect themselves and their equipment from blast, radiation, fire, etc., to be able to effectively operate in the immediate post-attack period.

Therefore, specific guidance is needed for local emergency preparedness planners and emergency services management personnel to assist them in preparing operational plans for an attack situation. Specific guidance is needed in the following areas:

a) Establishing goals and objectives for each of the three phases (crisis, trans-attack, and immediate post-attack). A part of this effort has been accomplished as a component of the research on the role of public safety agencies in crisis relocation. However, the protection of critical workers and facilities (including public safety resources) by a community's emergency forces has not been specifically addressed. For example, planners need a list of critical facilities in their community to be able to establish priorities for protection activities.

b) Determining when and where emergency forces should take shelter. Emergency personnel will be among the last to protect themselves and their equipment. How will they know when they must take shelter (e.g., source of information and communications link)? This function may be even more difficult in a multi-burst situation.

c) Identifying specific actions that emergency services can take during peacetime and crisis periods to prevent, or minimize, damage to the community in general and themselves in particular, should an attack occur.

d) Determining the type and quantity of resources that would be required to meet the established goals and objectives. Research has been accomplished concerning the establishment of resource requirements for a crisis relocation operation — in both the risk and the host areas. However, resource requirements for operation in an immediate post-attack environment (especially for protecting critical industries) have not been addressed.

e) Establishing operational procedures for use in the three phases.

These procedures will almost certainly be significantly different from routine procedures. For example, fire protection operational procedures may be entirely oriented toward the reduction of spread rather than the salvage of a particular occupancy.

f) Determining the capability of public safety facilities and equipment to service the blast/fire/radiation environment. It may be better, for example, to pull equipment (e.g., pumpers and bulldozers) back to some point (such as the 2 psi perimeter) and leave it in an open area, rather than to try to protect it in a hardened facility closer to the industries to be protected, but within an expected high overpressure area.

g) Identifying shelters to be used by public safety personnel; location, size, protection, etc. The location question is especially critical, because emergency services personnel need to be in the heart of the risk area immediately before, and after, a burst, which indicates a requirement for a close-in, heavily protected location. However, their equipment (especially firefighting and debris removal apparatus) must also be protected. And, this equipment is very large and may be sensitive to effects of a nearby burst.

Thus, a critical question is, "Should emergency forces be sheltered near the critical industries they need to protect, or, should they pull back to a safer point and attempt to return (through debris) to the area to be protected?" Of course, the answer to this question may vary by type of emergency service; that is, EMS and law enforcement personnel may stay near the blast area, while firefighting and debris removal forces pull back.

In summary, a planning guide (in some form) must be developed to assist emergency service organizations in preparing and following specific plans for the protection of critical facilities and personnel. This planning guide should be very carefully designed for use by local government public safety personnel, or it will remain on the shelf along with a lot of other "planning guides."

Task 6
CRITICAL RECORDS PROTECTION

Without the preservation of vital records, recovery of society after a major disaster could be severely impeded. These are records that are necessary for continued functioning of industry, services, and social order, and that are not immediately replaceable. Guidance is needed for the process of selecting vital records, and in developing protection techniques and equipment.

TASKS

1. Guidelines should be established for procedures to identify critical records.

Procedures should include (1) defining "critical"; (2) assigning responsibility for identifying critical records; (3) ranking records in order of importance.

a) Private Sector Records — Industrial processes, chemical formulations, blueprints, equipment specifications, maps showing locations of hazardous materials may all be considered essential by industries. If the facility has been hardened, locations and types of buried and otherwise "treated" equipment and hazardous materials should be recorded. Potential suppliers of fuel and other inputs should be documented.

b) Public Records — Information necessary for emergency services, such as fire department maps of hazardous material areas and manuals for hazardous material spill and fire response procedures should be preserved. Documentation of potential sources of medical supplies, such as hospitals and pharmacies, and sources of food, such as supermarkets, could be useful. County assessors' records documenting property ownership and building characteristics may be useful during recovery.

A record that should be removed to the host area is the one that describes the location of all critical records.

c) In addition to conventional records, there may be a need for "historic" records; that is documentation of older, less complex methods of production. There is the chance that, after a large-scale disaster, current sophisticated machinery and production methods would be unusable. For example, present-day methods of paper and steel production are highly automated and energy-intensive. These products can be made with less automation and more labor-intensive methods, yet the older methods are complex enough that records detailing ways to use parts from old machinery, hand tools, and other salvaged materials would be necessary.

2. Techniques and equipment for record protection should be developed and tested.

Once records have been designated as critical, decisions must be made on how they are to be protected. Factors that influence the choice of treatment method, such as the immediate environment, transportation capacity, capacity of appropriate storage equipment, availability of burial materials, and the volume of records to be protected, should be identified to encourage evaluation and modification.

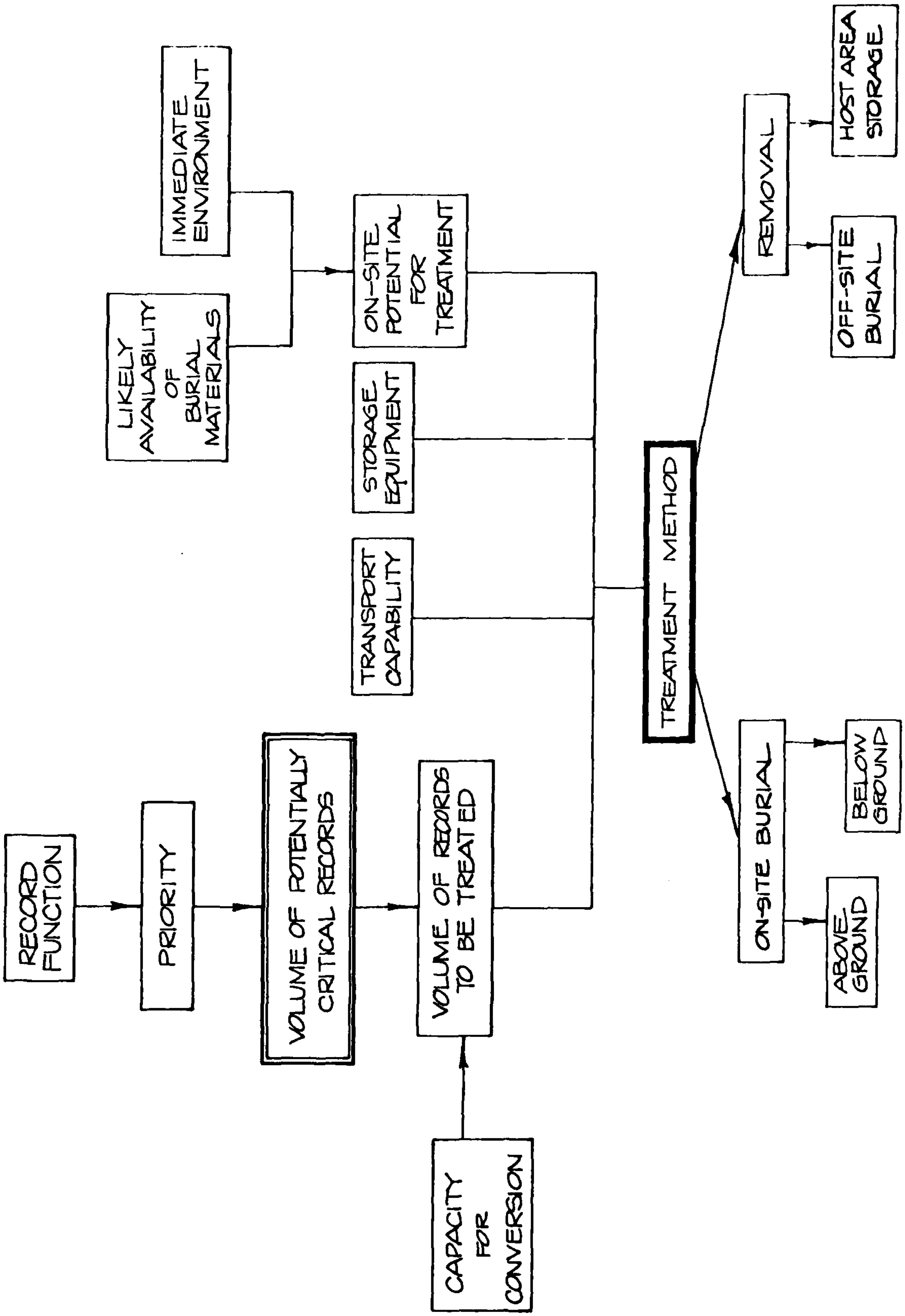
a) Possible Treatment Methods — onsite burial of containers of records could be practical for facilities with dirt yards, or those near open fields. Those surrounded by concrete could consider aboveground burial; that is, covering containers of records with sandbags, metal shavings, etc. Facilities with large quantities of critical records might consider building underground shelters for them. If record quantities are small and transport capabilities large, or if onsite methods are impractical, then removal of records to host areas for storage, or to other areas for burial, is possible.

b) Equipment — practical designs, materials and sizes of record storage containers should be developed, tested, and evaluated. Both portable and fixed types should be examined. Equipment should be resistant

to heat, pressure, impact, and moisture, yet should not require the employment of extraordinary means to open during recovery efforts.

c) Conversion — To maximize the number of records storable in a given container or shelter, inexpensive means of reducing the size of records should be explored. Reproduction of paper documents onto microfiche and other smaller forms may be desirable. However, specialized record forms such as computer discs, where information is only retrievable with specific equipment, may not be practical. Perhaps these should be converted to less specialized forms for storage.

A flow chart of the critical records protection process is presented on the following page.


RECORD FUNCTION
PRIORITY
VOLUME OF POTENTIALLY CRITICAL RECORDS
VOLUME OF RECORDS TO BE TREATED
CAPACITY FOR CONVERSION
TRANSPORT CAPABILITY
STORAGE EQUIPMENT
LIKELY AVAILABILITY OF BURIAL MATERIALS
IMMEDIATE ENVIRONMENT
ON-SITE POTENTIAL FOR TREATMENT
TREATMENT METHOD
ON-SITE BURIAL
ABOVE GROUND
BELOW GROUND
REMOVAL
OFF-SITE BURIAL
HOST AREA STORAGE

CONCLUDING REMARKS

As chairman I want to first thank all participants of Workshop 4 for their hard and diligent efforts. Particular thanks go to Mr. Jim Jacobs of FEMA, who assumed the job of co-chairman, and H.G. Ryland, who acted as recorder.

Two things are obvious from the deliberations of Workshop 4

1) There are many areas that need research

2) Very little has been and is being done.

As was noted many times during the conference, there needs to be a continuing commitment at the highest levels of government to the concerns of Civil Defense/Crisis Relocation, so that the needed research can be accomplished and we can receive the support of industry and the general public, which is absolutely essential to a viable program.

VII PROGRAM SUMMARY AND RECOMMENDATIONS

This chapter on program summary and recommendations in the 1979 conference report emphasized three points that stood out in the workshop deliberations of that conference.

- o First, general agreement with the program objectives generated in the preceding year (Asilomar, 1978).
- o Second, a need for guidance from some experts outside the blast/fire community, specifically to meet the urgent need to identify the critical facilities and key workers.
- o Third, the detrimental impact of fiscal constraints that limit the program effort to about half the recommended level.

These points are equally appropriate for the 1980 Conference. Only slight changes in the program recommendations were forthcoming, and these modifications reflect mainly the influence of the MILL RACE field event on scheduling and the associated necessity for reevaluation of task priorities in the face of an austere financial situation. Very little progress has been made toward defining the critical industries, utilities, and facilities; consequently, the identity of the key workers remains a mystery and the workshop discussions continue on a general plane without being able to bound or limit the types and/or locations of structures pertinent to the blast/fire problem. In terms of budget, the program continues at about half the recommended level, thereby emphasizing the need to sharpen our focus with respect to priorities.

The program elements recommended for FY81 and FY82 are summarized in Tables VII-1 and VII-2, respectively. Tasks are grouped according to workshop topics (i.e., the initial numeral in the task number refers to the workshop number); priorities within a group are indicated by capital letters commencing with A as the highest priority. Since priority comparisons between workshop recommendations can lead to disputes that cannot be resolved objectively in the existing conference format, except

when the results from one workshop's activities are clearly prerequisite to decisions and planning in another, priorities assigned the same letter are assumed equal. Three budget levels, optimal, moderate, and austere, are listed for each task. These should be interpreted as follows:

- Optimal--Given an adequate overall level of program funding, the task could be accelerated to this level without its rate of progress getting out of balance with other program elements and with a return still proportionate to the investment.
- Moderate--Lacking an adequate overall level of program funding this is the minimum funding that should be expended to keep the rate of progress from falling seriously below program goals.
- Austere--Below this level, it is probably not worthwhile doing anything on this task element of the program.

Table VII-1

REVISED FY81 BLAST/FIRE PROGRAM*

Task No. and Title	Contingent Budgetary Recommendations ($K) Optimal	Moderate	Austere	Priorities
Shocktube Fire Extinction Study				
1.1 Shocktube Experiments (2564A continuation)	200	150	150	A
1.2 Carbon Rod Thermal Source (2564B continuation)	50	50	20	A
1.3 Test Matrix Definition and Data Correlation	50	50	30	A
MILL RACE Fire Extinction Tests				
1.4 Debris (class-A Fuel) Experiments	119	119	100	B
1.5 Class-B Fuel Verification Tests	195	195	195	C
Support Studies				
1.6 Theory of Airblast Extinction (2563E continuation)	150	100	50	C
1.7 Soviet Blast/Fire Literature Review	50	30	30	C
Structure/Debris Response Analysis				
2.1 Analyze City Complex (Crude Cut)	160	70	50	A
2.2 Predict Debris Distribution (2564C continuation)	100	70	50	A
MILL RACE Structural Tests				
2.3 Expedient and Upgraded Shelter (FEMA)	105	105	105	B
2.4 Key Worker/Host Area Shelter and Industrial Hardening(SSI)	582	582	250	A
2.5 Response of Structures and Debris Translation (SRI)	454	454	250	A
Firespread and Threat Definition				
3.1 Mass Fire Environment (2564E continuation)	120	100	80	A
3.2 Upgrade Urban Fire Spread Model+	-	—	—	-
3.3 Fire Vulnerability of Critical Resources	200	180	150	B
Countermeasures				
4.1 Key Worker Shelter Criteria	75	60	45	A
4.2 Protection/Relocation of Key Equipment	75	60	45	B
Planning Services				
5.1 Asilomar Conference	40	40	40	A
5.2 Sensitivity Study and Long-Range Planning	40	20	10	B
Totals	2765	2435	1650	

* Assumes update of secondary fire model is completed with FY 1980 funds.

\+ Should await better definition of initial fire distribution and state.

Table VII-2

TENTATIVE FY82 BLAST/FIRE PROGRAM*

Task No. and Title	Contingent Budgetary Recommendations ($K) Optimal	Moderate	Austere	Priorities
Airblast Extinction				
1.1 Experiments in CP Thermal/Airblast Facility (2564A cont)	300	200	100	A
1.10 Tests Supplemental to CP Effort	200	100	50	B
1.3 Theory Development/Application	250	150	100	B
1.4 Post MILL RACE Analysis+	—	—	—	—
Enclosure & Fuel Complex Responses				
1.40 HE and TRS Experiments	750	400	100	B
1.60 Predictive Initial Fire Model	40	40	40	A
Thermal Simulation				
1.20 CARRS Modifications	75	50	30	C
1.21 Field Sources	400	200	100	D
One-City Study Model Exercise				
1.9, 2.4 Initial Fire Predictions in Blast-Damaged Urban Area	200	125	80	A
Structure/Debris Response				
2.1 Analyze City Complex (refined cut)	150	100	80	A
2.2 Predictive Debris Distribution Model	150	100	80	A
2.3 Post MILL RACE Analysis	100	75	50	A
Firespread and Threat Definition				
3.1 Mass Fire Environment (target specific)	120	100	80	A
3.2 Urban Spread Model	120	100	80	B
Countermeasures				
4.3 Optimization of Fire Mitigation	100	80	60	A
Program Planning and Services				
5.1 Asilomar Conference and Long Range Plans	80	60	50	A
1.70 International B/F Literature Survey	75	50	25	C
Totals	3110	1930	1105	

*This program anticipates a substantial level of support from DNA to supplement FEMA funding.
+No requirement in airblast extinction is expected.

Appendix A

CRITERIA FOR DETERMINING THE ESSENTIAL INDUSTRY AND KEY WORKERS DURING CRISIS RELOCATION

By: Richard K. Laurino

An Invited Paper Presented At The
Conference on Blast and Fire Interactions,
Asilomar, California, May 19, 1980

19 May 1980

Sponsored by: Federal Emergency Management Agency

Center for Planning and Research, Inc.
2483 East Bayshore Road, Palo Alto, California 94303

Introduction

It has been generally recognized that specific criteria relating to essential industry and key workers are needed to provide the basis for systematic research on industrial protection and personnel shelter requirements. At the present time, no definitive studies and guidance exist. The federal government has provided state emergency planners with interim guidance by identifying types of industry to be considered essential, and some research studies have addressed the problem peripherally as part of some other study. The material presented here is an amalgam of information gathered from federal and state planners and information on essential industry developed at the Center for Planning and Research as part of a study of the economic impact of crisis relocation.

Discussion

A requirement would exist during crisis relocation for some continued provision of essential goods and services. The term "essential industry" has been applied to industrial sectors that produce or provide such essentials as demonstrated in Exhibit 1. Further considerations suggest that if demands are controlled and/or existing inventories are used, not every facility in an essential industrial sector would need to continue production during crisis relocation. Thus a "slack" in production capacity should exist which can be used with proper planning to reduce the hazards to those employees that continue to work during this period (i.e., key workers). One way to accomplish this is to maximize essential production in nonrisk areas so as to reduce required production in risk areas. Another approach is to reduce the staff of each essential production facility to the core group needed to produce essential products for a short period.

The possibilities for reducing demand will depend upon the national objectives during crisis relocation. An objective of supporting relocation would require only subsistance production from a few industries. Preparations for support of postattack operation would establish requirements for more production in other heavy industry sectors. Significant support of military activities over the crisis relocation period would require an expanding level and variety of industrial production.

Exhibit 1

ESSENTIAL INDUSTRY

REQUIREMENT FOR CONTINUED PRODUCTION

ESSENTIAL AND NON-ESSENTIAL INDUSTRY

RISK AND NON-RISK AREAS PRODUCTION

ACTIVITY LEVELS FOR ESSENTIAL INDUSTRY
- DEMANDS
- INVENTORIES

NATIONAL OBJECTIVES
- SUPPORT RELOCATION
- SUPPORT POST ATTACK OPERATIONS
- SUPPORT MILITARY ACTIVITIES

A possible list of essential industries is shown in Exhibit 2. The list of industries is organized to show the basic group associated with supporting relocation with increments required for other possible postattack objectives. It should be noted that activities other than manufacturing are included. In particular, transportation and government services could account for a significant percentage of key workers.

Inventories could be a significant determinant of the level of required risk area production. Many manufactured goods could be supplied in part or in whole by existing inventories. On the other hand, crisis relocation could end in an attack, and thus the reduction of inventories might not be advisable. This is a policy issue that deserves careful consideration.

The issue of identifying industries as essential or nonessential is far from resolved. The federal government is providing initial guidance to state and local authorities for use in preliminary planning for crisis relocation. Exhibit 3 indicates the kinds of industries on the essential list in one locality used as a test area for FEMA contractors.

If the objective is to limit the number of workers required in risk areas, it would appear desirable to reduce this list considerably. One approach to reducing the list would be to depend more heavily on services located in host areas. Another approach would be to severely limit demand so that many of these industries could be closed entirely in risk areas.

Further reductions in workers could be accomplished by identifying in each facility those workers actually required to produce needed goods and services over the short term. Presumably, many financial, maintenance, administrative, and other activities could be eliminated during the crisis relocation period. Exhibit 4 shows summary results of a telephone survey made by the local emergency services office in Colorado Springs.

A comparison of data in the first two columns ("average employees" and "average key employees") indicates that in most industries virtually all employees were believed to be essential. This result must be considered suspect. Clearly more time and more detailed survey techniques would be required to obtain reliable answers. Several discussions participated in by industry personnel and Center staff tend to indicate that for many industries the number of key workers should only be a small fraction of total employees.

Exhibit 2

ESSENTIAL INDUSTRY REQUIREMENTS

	PRODUCTION	INVENTORY
SUPPORT RELOCATION		
FOOD PRODUCTS AND SERVICES	X	X
HEALTH SUPPLIES AND EQUIPMENT	X	X
CLOTHING		X
ELECTRIC POWER	X	
FUEL PRODUCTS AND SERVICES	X	X
WATER, SANITATION, & SEWAGE TREATMENT PRODUCTS & SERVICES	X	X
CONSTRUCTION MATERIALS, EQUIPMENT AND SERVICES	X	X
TRANSPORTATION SERVICES	X	
TELECOMMUNICATIONS SERVICES	X	
FINANCIAL SERVICES	X	
GOVERNMENT SERVICES	X	
HEALTH AND MEDICAL SERVICES	X	
WHOLESALE & RETAIL SERVICES	X	
MISCELLANEOUS EMERGENCY PRODUCTS (BATTERIES, ETC)	X	X
POST ATTACK RECOVERY ADD:		
PRODUCER EQUIPMENT AND COMPONENTS	X	X
INDUSTRIAL FACILITY COMPONENTS	X	X
INSTRUMENTS	X	X
OTHER LOGISTIC SERVICES	X	
SELECTED NON DURABLES	X	X
MILITARY SUPPORT ADD:		
ORDNANCE	X	X
OTHER MILITARY EQUIPMENT AND SUPPLIES	X	X
BASIC INDUSTRIAL SECTORS	X	X

Exhibit 3

TELEPHONE SURVEY OF INDUSTRIES IN COLORADO SPRINGS*

BAKERY (Wholesale)
BOTTLERS
DAIRY (Wholesale)
FUEL
GASOLINE (Wholesale)
OIL
GROCERS (Wholesale)
MEAT PACKING
PRODUCE
AIRCRAFT SERVICING/MAINTENANCE
AMBULANCE
BEARINGS
BLOOD BANKS
BOILER REPAIRING
BRAKE SERVICE
BURGLER ALARM SYSTEMS
CEMETERIES
COMMUNICATIONS/UTILITIES
- Newspaper
- Public Service
- Primary Radio Stations
- Telephone
- Television
- Electric Light and Power
- Gas Company
- Printers
- Communication Equipment
- Printing Supplies
- Contractor's Equipment & Supplies-Rental

TRANSPORTATION
- Air
- Rail
- Taxi
- Trucking

DATA PROCESSING EQUIPMENT
DATA PROCESSING SUPPLIES
ELECTRIC MOTOR REPAIR
ELECTRONIC EQUIPMENT/SUPPLIES
ENGINES, DIESEL REPAIR
FIRE ALARM SYSTEMS
FUNERAL DIRECTOR
FURNACES, SUPPLIES/PARTS
HOSPITALS
ICE
INDUSTRIAL GASES
LABORATORIES, MEDICAL
MACHINE SHOPS
PEST CONTROL
PLUMBING WHOLESALE/MANUFACTURING
REFRIGERATING EQUIP. PARTS/SUPPLIES
RENDERING COMPANY
TOILETS, PORTABLE
WELDING
WELDING EQUIPMENT/REPAIR
WELDING EQUIPMENT/SUPPLIES
MANUFACTURING
- Aircraft Equipment, Parts & Supplies
- Aluminum Foundries
- Automotive
- Boxes
- Carburetors
- Chemicals
- Contractors/Construction
- Electrical/Industrial Apparatus
- Electronics
- Fabricating-Lubricating
- Farm Machinery
- Glass
- Machine Parts
- Oil Wholesalers
- Optical Instruments
- Packing & Crating Services
- Paper Products
- Paving Mixtures & Blocks
- Pharmaceutical
- Prestressed Concrete
- Pumps
- Solvents
- Steel Distributors
- Steel Fabricators
- Warehouse (Storage)

*Colorado Springs Civil Defense Office

Exhibit 4

DATA FOR SELECTED COLORADO SPRINGS INDUSTRIES

Type Industry	Employees (average)	Key Employees (average)	Resupply Time (days)	No. of Vehicles (average)	Vehicle Fuel Supply (days)
Bakeries (wholesale)	21	NA	1	17	21
Dairies (wholesale)	38	37	1	26	5
Gasoline (wholesale)	8	8	1	8	NA
Grocers (wholesale)	30	30	7	7	0
Meat Packers	16	16	10	6	14
Produce	16	16	1	3	15
Ambulance Service	28	28	NA	9	21
Trucking Service	8	8	NA	12	0
Hospitals	660	640	Variable	0	0
Packing and Crating	30	30	NA	18	7
Boxes	14	5	30	2	NA
Banking	75	40	NA	2	0
Sheriff's Dept.	200	150	7	71	7
Utilities (power)	345	300	NA	46	0

NA - not available

To establish the approximate number of key workers needed in risk areas, a preliminary examination was made of selected metropolitan areas. For relocation support, Exhibit 5 indicates that key workers (as a percentage of all workers) ranged from 4.5% to 7.1%. These estimates were based on key worker estimates in manufacturing industries (e.g., food and health supplies) made earlier by the Office of Industrial Mobilization and on estimates made by CPR for government emergency services (e.g., police, fire, and utilities) and industrial support services (e.g., transportation and warehousing). Earlier estimates made at the Center for Boston and New York, which included financial service workers, were in the 7% range. Later work suggested that most financial activities in risk areas probably could be shut down during the crisis relocation period.

It should be noted that the numbers of key workers in these estimates were about equally divided among manufacturing, industrial support services, and government emergency services. One of the implications for shelter protection is that while the manufacturing employees might work in one location, service and government workers would likely be mobile. Thus a problem (or an opportunity) arises as to where shelter for these latter groups might be located. For instance, it might be worth considering location of shelter for these groups in outlying portions of risk areas with "tactical warning" provided by radio.

If the other risk areas exhibited the same characteristics as the sample of areas examined, one would expect a requirements for about 3 million to 4 million key worker spaces in the United States. However, the estimates still do not consider the possibilities for reducing risk area essential production by increasing host area production, or for reducing staffs of essential facilities, services or government activities.

Specific demands for production have not yet been established for a crisis relocation period although, as indicated earlier, these demands would depend upon national objectives. Exhibit 6 provides some examples of demands for several sectors based on earlier work on problems of postattack survival and recovery. The IDA subsistence requirements are closest to the requirements for crisis relocation support. All demand examples indicate that only a portion of industrial production in essential sectors would be

Exhibit 5

KEY WORKERS IN SELECTED METROPOLITAN AREAS (1975)

AREA	POPULATION (THOUSANDS)	KEY WORKERS AS A PERCENTAGE OF ALL WORKERS
New York	9,562	4.5
Boston	3,373	4.7
San Antonio	982	7.1
Springfield-Chicopee-Holyoke	549	5.5
Utica-Rome	334	5.0

Exhibit 6

NATIONAL REQUIREMENTS AND NON-METROPOLITAN MANUFACTURING CAPACITY

			REQUIREMENTS		
SIC CODE	SECTOR	NON-MET CAPACITY (%)	SUBSISTENCE (PARM) (%)	SUBSISTENCE (IDA) (%)	RECOVERY (IDA) (%)
20	FOOD PROCESSING	34.7%	56%	52%	56%
28	CHEMICALS	24.7	7	7	33
(284)	DRUGS	(9.3)	–	–	–
(287)	AGRICULTURAL CHEMICALS	(36.7)	–	–	–
29	PETROLEUM REFINING	17.3	21	9*	58
33	PRIMARY METALS	22.5	4	2	32
34	FABRICATED METALS	22.6	7	5	40
35	MACHINERY (LESS ELECTRICAL)	25.0	1	1	27
36	MACHINERY (ELECTRICAL)	24.5	3	1	17
37	TRANSPORTATION	18.0	1	–	12

* *Add 2% for key worker commuting.*

required, which tends to confirm the suggestion that slack could exist in essential production sectors. Thus, with proper planning, not all essential industry in risk areas need remain in operation during the crisis relocation period.

In the Center's work on the economic impact of crisis relocation, a number of possibilities for reducing risk area production in the food industry were examined. Exhibit 7 indicates estimated required risk area production for 32 food products at the national and state level of aggregation. The "normal production" assumes use of peacetime production capacities. "Emergency capability" includes expansion of nonrisk area production to emergency capacity levels and reasonable substitution of products to meet minimum demands. While the results are highly variable from product to product -- and also would be highly variable from state to state -- they do suggest that a significant reduction in risk area production of food items is possible while meeting minimum demands of the population. Depending upon assumptions, total key workers in food production at the national level might be reduced to between 6% and 33% and those for the state of Colorado to between 20% and 38%. The national results are probably optimistic in that they assume essentially perfect allocation of products throughout the United States. On the other hand, these results do not include the further reductions possible through more precise identification of key workers within the staffs of each essential facility.

Conclusions

While examinations of essential industry and key workers issues have been fragmentary and preliminary in nature, some tentative conclusions appear possible at this time:

- Since key workers will need expensive blast protection (preferably special purpose blast shelters) a significant planning effort to minimize the number of key workers in risk areas would be warranted.

- Current evidence suggests that the number of key workers could be greatly reduced by further limitations on types of industry considered essential, by greater use of nonrisk area production, and by more careful identification of key workers on facility staffs.

Exhibit 7

COMPARISON OF COLORADO STATE AND NATIONAL RESULTS
FOR REQUIRED RISK AREA PRODUCTION*

Product	Name	Normal Production A State	Normal Production B National	Emergency Capability C State	Emergency Capability D National
1	Meat products	45%	18%	43%	0%
2	Butter	20	neg	0	0
3	Cheese	76	60	76	0
4	Evaporated milk	0	66	0	5
5	Ice cream	12	0	2	0
6	Fluid milk	89	85	78	42
7	Canned sea foods	0	28	0	0
8	Canned specialties	30	9	30	0
9	Canned fruits, veg.	0	83	0	30
10	Dehydrated food	56	42	56	0
11	Pickles, sauces, dressings	18	0	7	0
12	Fresh or frozen fish	0	0	0	0
13	Frozen fruits, veg.	27	26	0	0
14	Flour & cereal prep.	51	30	50	0
15	Animal feeds	0	2	0	0
16	Rice milling	0	22	0	0
17	Wet corn milling	0	0	0	0
18	Bakery products	50	35	48	3
19	Sugar	0	0	0	0
20	Confectionery	0	0	0	0
21	Alcoholic beverages	0	0	0	0
22	Soft drinks	12	0	0	0
23	Extracts, sirups, n.e.c.	24	neg	24	0
24	Cottonseed oil mills	0	0	0	0
25	Soybean oil mills	0	0	0	0
26	Veg. oil mills, n.e.c.	18	0	18	0
27	Animal fats and oils	29	0	28	0
28	Roasted coffee	24	5	24	0
29	Cooking oils	0	4	0	0
30	Manufactured ice	0	0	0	0
31	Macaroni/spaghetti	73	67	73	46
32	Food preparations, n.e.c.	17%	0%	8%	0%

n.e.c. - not elsewhere classified   Neg - negligible

*Column A from Table 11, column B from Table 8, column C from Table 12, column D from Table 10.

- Initial calculations indicate that a large percentage of those persons considered to be key workers will be mobile and will be dispersed over the entire risk area. This evidence suggests that the key worker shelter plan might include shelters at selected manufacturing facilities and other shelters dispersed to the outer reaches of risk areas.

- The type of industry and the number of key workers are highly dependent upon national objectives. The full implications on industrial preparedness planning of alternative objectives have not as yet been examined.

Appendix B

STATUS OF RADIANT SOURCE DEVELOPMENT

J.E. COCKAYNE
J.L. MEISNER

PRESENTED

19 MAY 1980

FEMA BLAST/FIRE INTERACTIONS CONFERENCE

SCIENCE APPLICATIONS, INCORPORATED

8400 Westpark Drive, McLean, Virginia 22101

OUTLINE

FOCUS OF BRIEFING: DEVICE FOR FEMA/SRI SHOCK TUBE

- BACKGROUND
- ALTERNATIVES
- CARBON-ROD RADIANT SOURCE (CARRS) BENCHMODEL
- TEMPERATURE VS. TIME FOR PARAMETRIC POWER LEVELS
- MOVIE OF SAICARRS
- PROTOTYPE DESIGN
- INSTRUMENTATION
- SCHEDULE
- FUTURE SAICARRS DEVELOPMENT OPTIONS
- RELATIONSHIP TO OTHER FACILITIES

BACKGROUND

FEMA/SRI SHOCK TUBE (30") SIMULATES 1MT AIR BLAST

DNA HE SHOTS PROVIDE 1T UP TO 1 KT SHOCKWAVES

SOLAR FURNACES ARE INCOMPATIBLE WITH SHOCK SYSTEM

LARGE AREA IRRADIATOR BEING DEVELOPED BY DNA (1981 IOC)

HIGH FLUX IRRADIATOR BEING DEVELOPED BY DNA (1981 IOC)

IGNITION OF 1' X 3' SAMPLE REQUIRES 0.3 MJ ON SAMPLE

ALTERNATIVES

RADIATORS

- PLASMA ARC (FLASHLAMP, CARBON ARC)
- FILAMENT (CARBON, TUNGSTEN)
- SEEDED FLAME (AL AND O_2, INERT RADIATING PARTICLES IN GASEOUS FLAMES)

POWER SUPPLIES

- BATTERIES AND CAPACITORS
- LINE SERVICE
- ADVANCED PULSED POWER DEVICES

FLUX DIRECTOR

- IMAGING VS. NON-IMAGING OPTICS
- STATIONARY VS. MOVEABLE REFLECTORS

CARBON-ROD RADIANT SOURCE (CARRS) BENCHMODEL

RADIATOR

- SIX-INCH WELDING ROD (NO COVERING, SINGLE SHOT, REPRODUCIBLE, NEAR-SUBLIMATION TEMPERATURE)
- WATER-COOLED CONNECTORS (CLAMP TYPE, NON-RIGID)

POWER SUPPLY

- SERIES OF 12 VDC BATTERIES ($\sim$1000A MAX, HIGH ENERGY, REDUCED LOAD VOLTAGE, COMMERCIAL PRICE)
- HEAVY DUTY CABLING, PARALLEL SOLENOIDS, CIRCUIT BREAKER

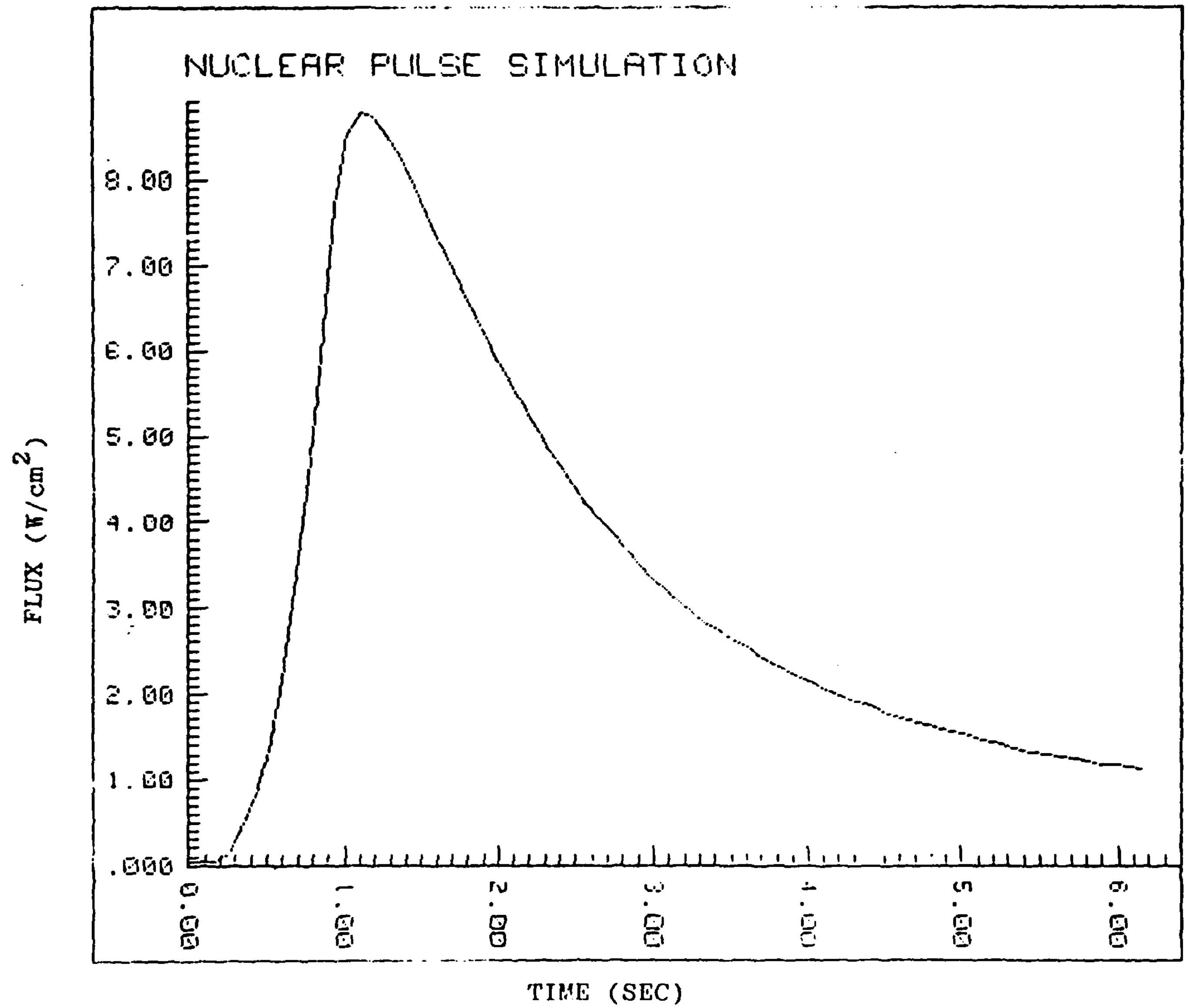
FLUX DIRECTOR

- PARABOLIC REFLECTOR WITH SOOT SLIT (ONE PER ROD)
- ELLIPTICAL REFLECTOR (ALZAK ALUMIUM, TWO PER SYSTEM)

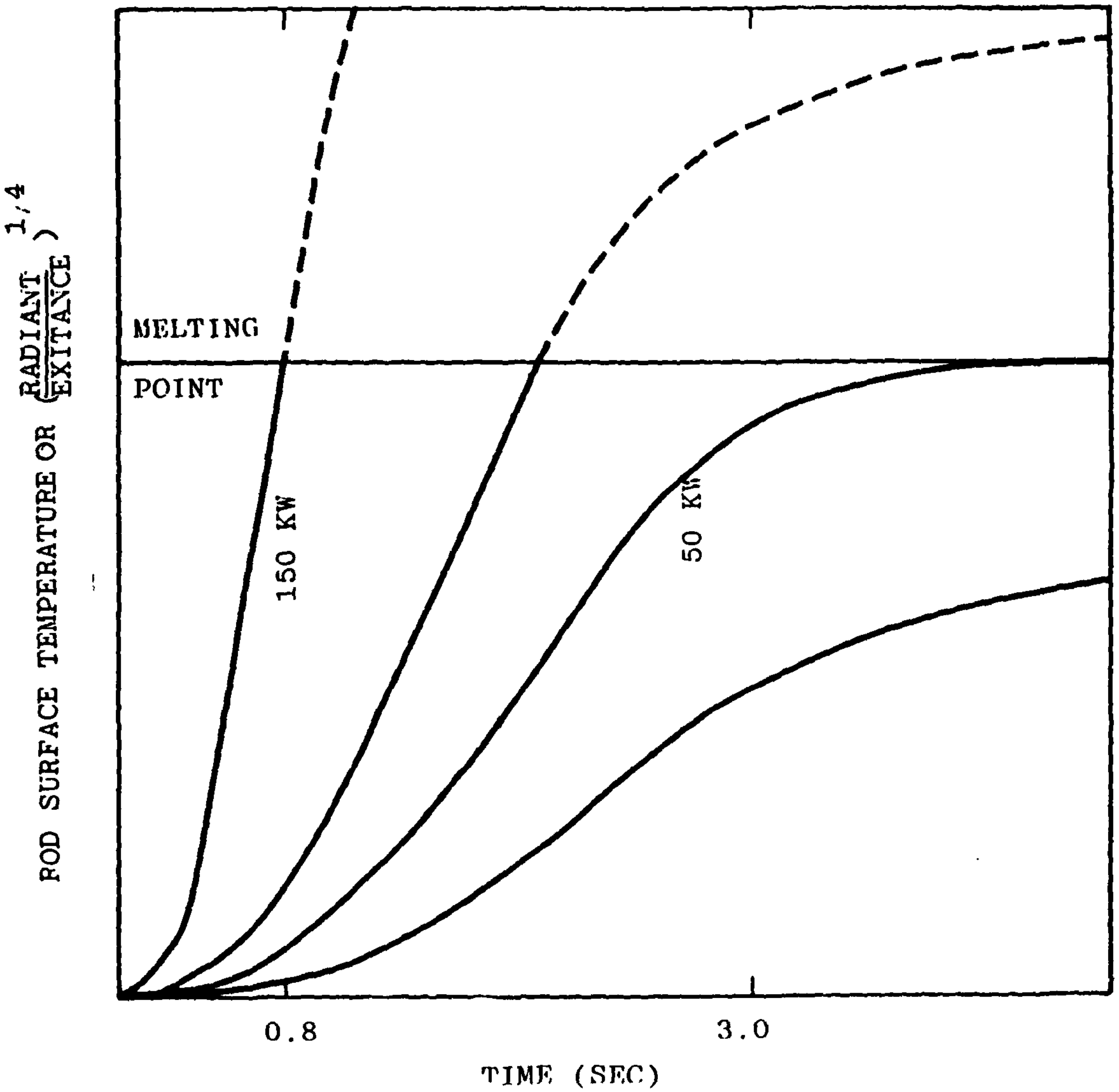
CONTROLLER/DATA ACQUISITION

- HP SYSTEM 45 WITH INTERFACES

LOW POWER PULSE PRODUCED WITH DEVELOPMENTAL CARBON-ROD RADIANT SOURCE



TEMPERATURE VS. TIME FOR PARAMETRIC POWER LEVELS



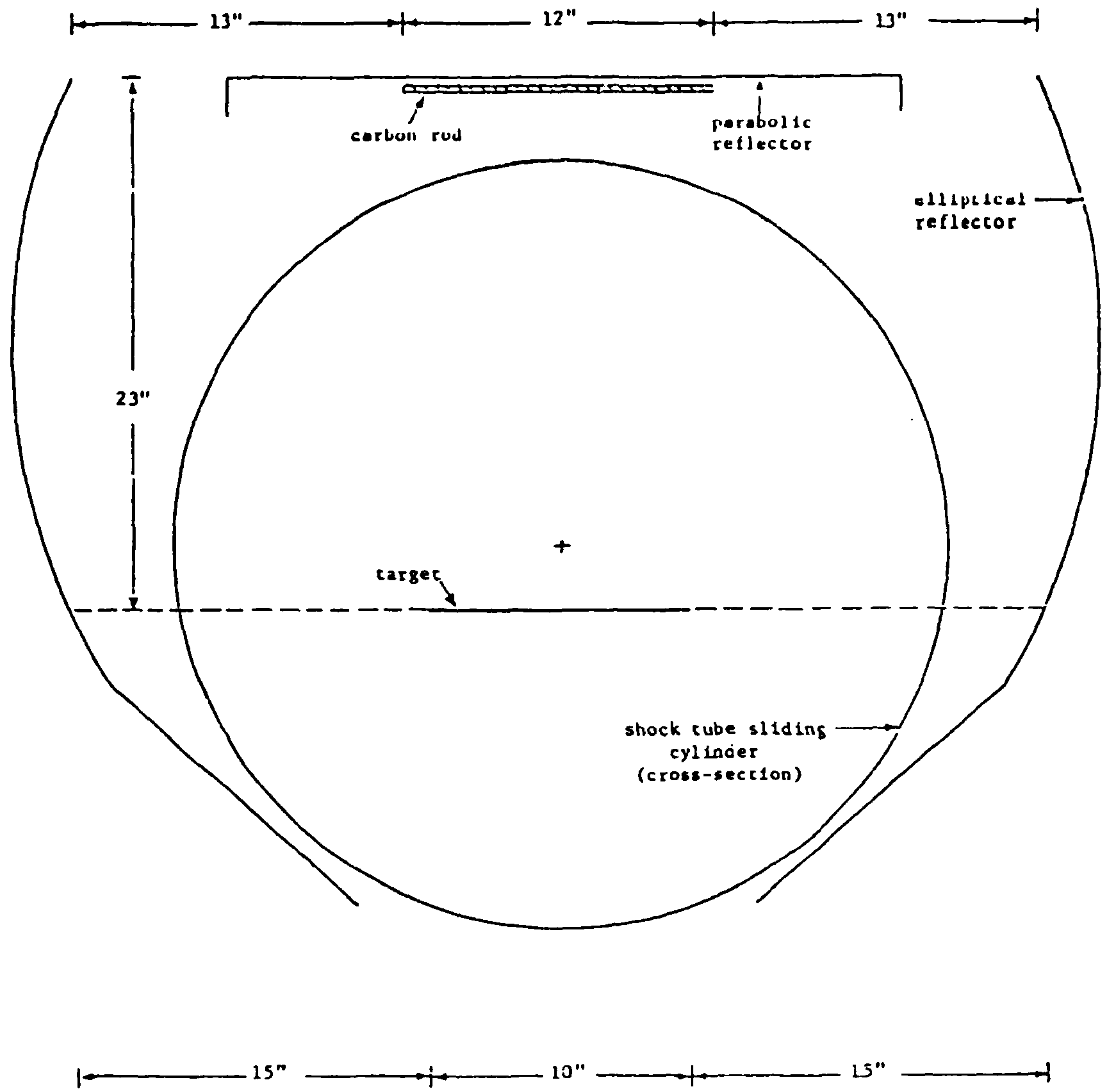
PROTOTYPE DESIGN

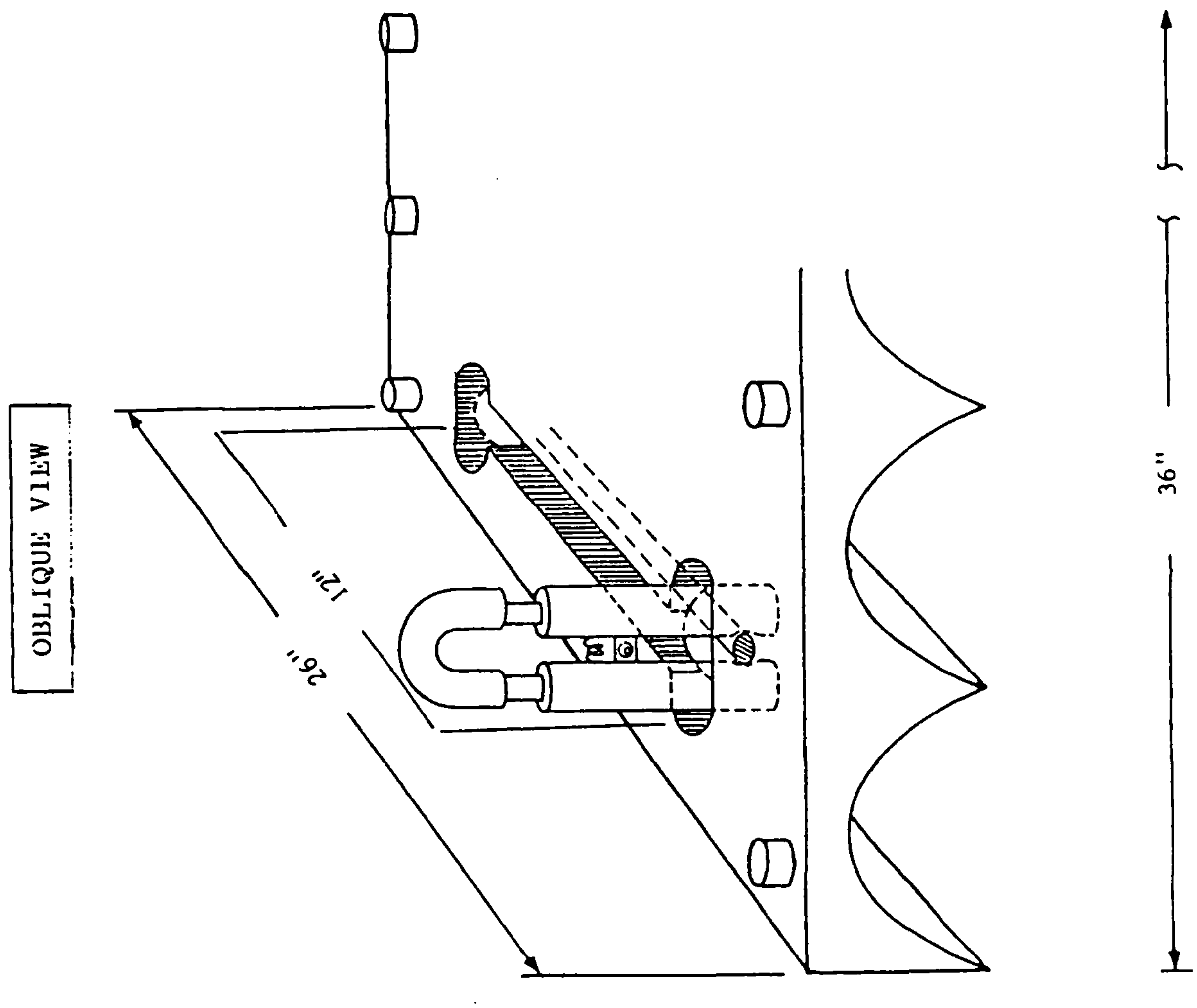
DRAWINGS FOR

- CROSS-SECTION THROUGH SHOCK TUBE
- OBLIQUE VIEW
- SIDE VIEW (ROD CLAMPS)
- END VIEW (ROD AND REFLECTORS)
- TOP VIEW

CARBON-ROD RADIANT SOURCE FOR SRI/FEMA

(CROSS-SECTION THROUGH SHOCK TUBE)




OBLIQUE VIEW
26"
12"
36"

AD-A098 579 SRI INTERNATIONAL MENLO PARK CA F/G 18/3

BLAST/FIRE INTERACTIONS, ASILOMAR CONFERENCE, MAY 1980.(U)

FEB 81 R S ALGER, S B MARTIN DCPA01-78-C-0279

UNCLASSIFIED NL

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END

DATE FILMED

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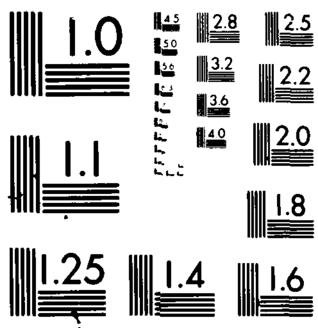
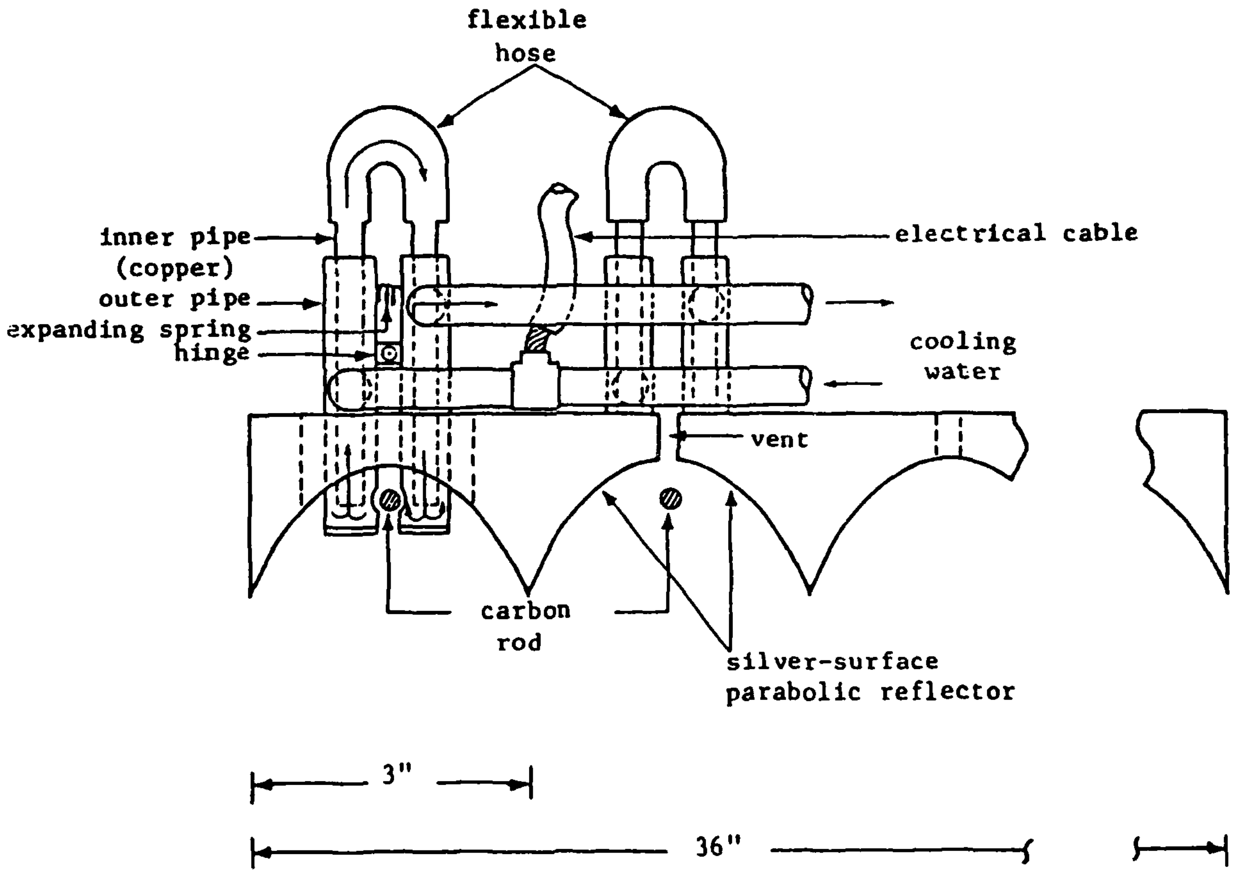


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

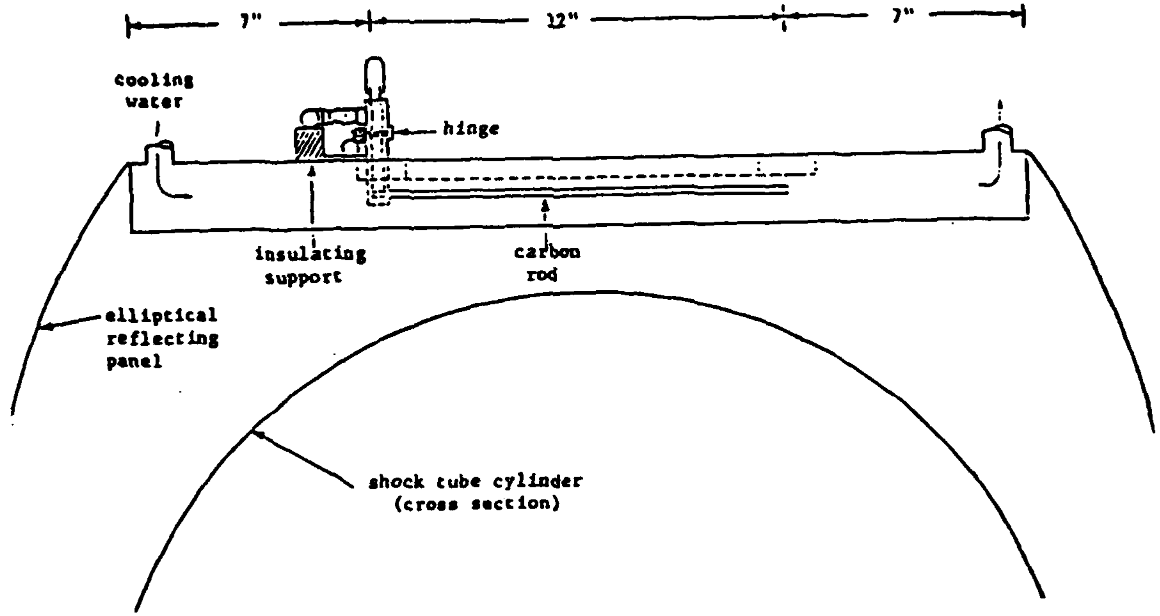
SIDE VIEW

(ROD CLAMPS)

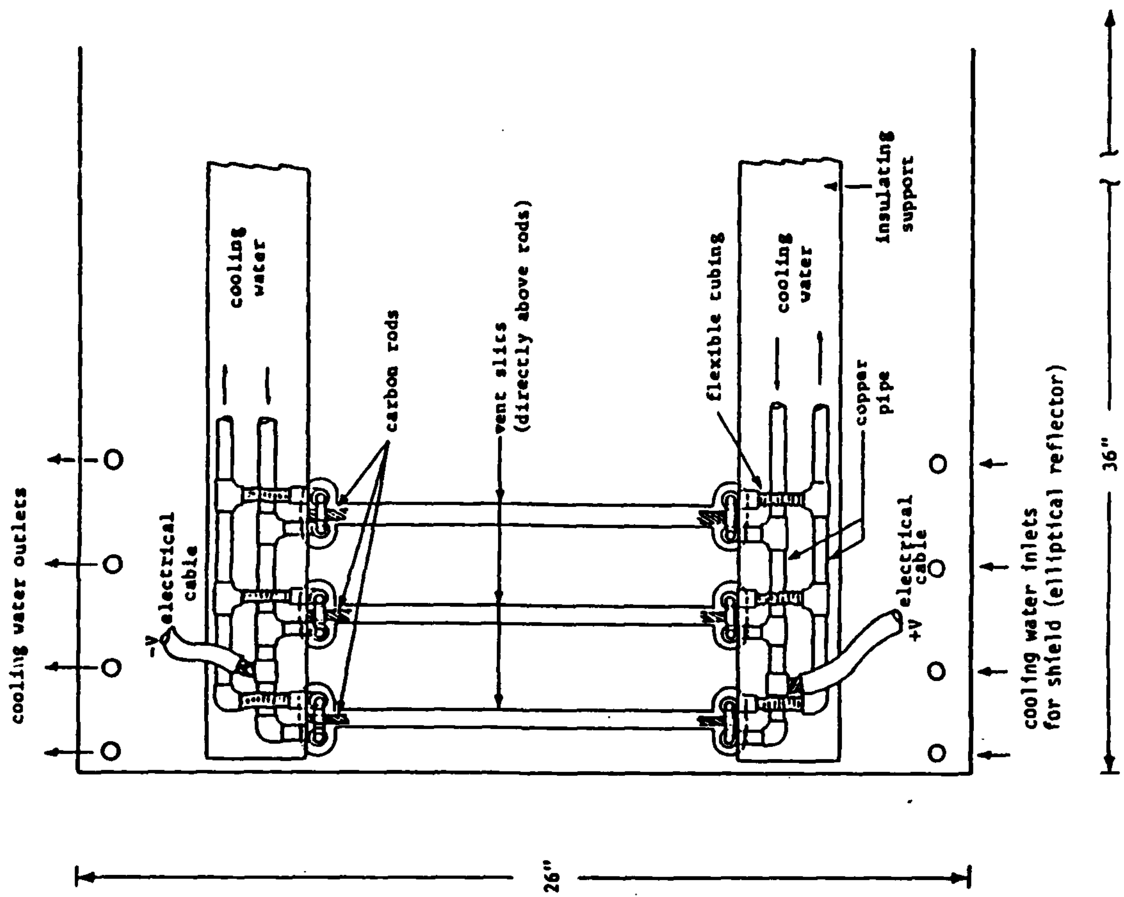


END VIEW

(ROD AND REFLECTORS)

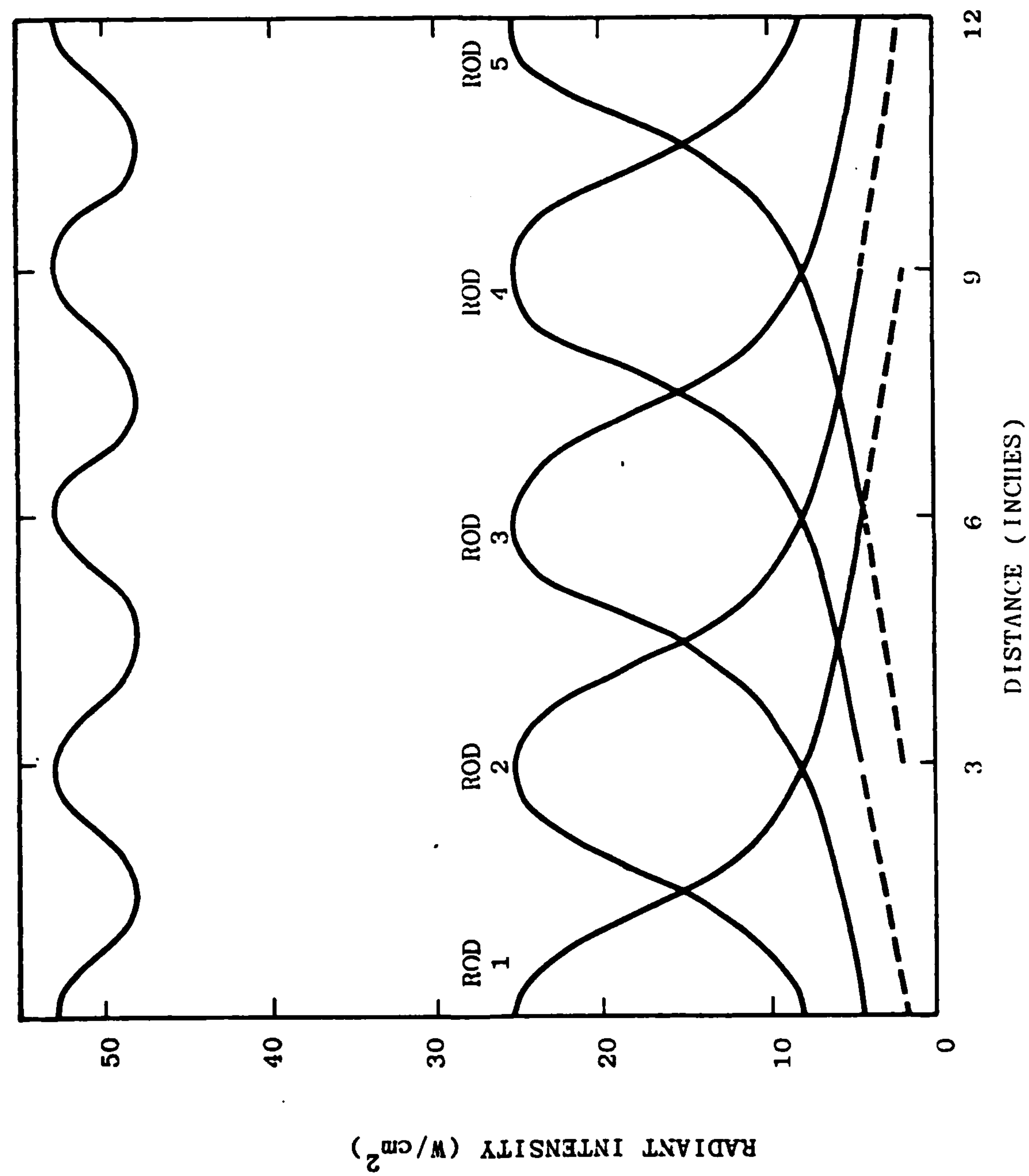


TOP VIEW


cooling water outlets
-V
electrical cable
cooling water
carbon rods
vent slits (directly above rods)
flexible tubing
cooling water
copper pipe
electrical cable
+V
insulating support
cooling water inlets for shield (elliptical reflector)
36"
26"

COMBINED FLUX AT TARGET SURFA FOR ARBITRARY POWER LEVEL

(P-P RIPPLE = 11%)



INSTRUMENTATION

VOLTAGE DIVIDER FOR EACH ROD

HIGH AMPERAGE SHUNTS FOR EACH CIRCUIT

FLOWMETERS FOR CRITICAL LOCATIONS

HY-CAL FLUX CALORIMETERS (FOUR FOR OPTIMUM PERFORMANCE MONITORING POINTS)

THERMOCOUPLES (AS APPROPRIATE)

SCHEDULE

BENCHMODEL:	FINISHED
PROTOTYPE MODULE:	FY80 FUNDING SOON, TECHNICAL DISCUSSION WITH FEMA/SRI BEFORE FINAL DESIGN, 31 AUGUST COMPLETION
MULTIPLE MODULE:	CDR AFTER 1 SEPTEMBER, JOINT SAI AND SRI INTERNATIONAL INSTALLATION AND FINAL CHARACTERIZATION IN EARLY FY81

FUTURE SAICARRS DEVELOPMENT OPTIONS

BRIGHTER FLUX (HIGH COLOR TEMPERATURE)

- OPERATE STEADILY AT NEAR-SUBLIMATION TEMPERATURE ($\sim$3800K)
- ADD FLUX SHAPING SHUTTER (SIMILAR TO SOLAR FURNACES)

HIGHER PEAK FLUX (FASTER IGNITION; LOWER YIELD)

- OPERATE CIRCUIT AT MAX POWER TRANSFER
- ADD MORE RODS

BATTERY REPLACEMENT (PERMANENT ENERGY SYSTEM)

- RECONFIGURE RESISTANCE ELEMENTS
- ADD HOMOPOLAR PULSED POWER SUPPLY

VARY ANGLE OF INCIDENCE OF RADIATION

- CHANGE ROD POSITION
- ADD A NEW REFLECTOR

RELATIONSHIP TO OTHER FACILITIES

DNA AL/LOX

- MILL RACE BLAST/THERMAL CAPABILITY (1 OCTOBER 1981)
  - SAME COLOR SPECTRUM PERMITS LARGE SAMPLE TEST
  - DESIGN BY SRI FOR 1KT BLAST

DNA FLASHLAMP

- DNA SOIL BLOWOFF AND BMD MATERIALS STUDIES (LATE 1981)
  - HIGHER COLOR TEMPERATURE PERMITS 1 FT^2 INCIPIENT
  - FIRE EQUIVALENCE INVESTIGATION

SANDIA THUNDERPIPE OR EQUIVALENT

- WITH ADDITION OF 1 MT BLAST CAPABILITY
  - ENLARGE CARRS BY 10-30 TIMES FOR SUBSCALE
  - MODEL/BUILDING EXPERIMENTS

Appendix C

7729-14 June 1979

CRISIS RELOCATION
INDUSTRIAL HARDENING PLAN
Phase I

Final Report

prepared for

Defense Civil Preparedness Agency
Washington, D.C. 20301

Contract No. DCPA01-77-C-0228
Work Unit 1124C

Dr. Michael A. Pachuta, COTR

by

J.V. Zaccor, G. Kamburoff, C. Wilton

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EXECUTIVE SUMMARY

A prototype manual has been developed for the Defense Civil Preparedness Agency by Scientific Service, Inc. to provide industry with a procedure to reduce its vulnerability to nuclear attack. This Industrial Hardening Manual contains a systematic format by which industrial managers can rank priorities for actions to reduce equipment vulnerability in their plants according to their own perceptions of relative importance of such equipment to production. It is anticipated that advance preparation and planning would enable the hardening process to be completed quickly during a crisis period signaled by worsening international relations.

The intent of the manual is to provide a versatility in application that will be oompatible with a wide range of conditions. The most demanding of these conditions is that with the shortest time for response. Nevertheless, a general approach need not depend on response time, though what is accomplished will. Factors that are within immediate plant control are detailed in 10 booklets. These booklets enable management to expedite the process, even on short notice if necessary (72 hours), by parceling out tasks to management-designated leaders; data forms are included. one of the booklets provides a preliminary set of hardening concepts so that management can match available manpower, materials, and equipment resources on a priority basis to the ranking hardening tasks.

Factors outside immediate plant control, but critical to operations, are the utilities and supplies of raw materials needed for production. Utilities and raw materials producers are recognized as industries that must themselves harden to survive. But the critical dependence of industry on utilities will require each plant to give serious thought in planning to alternate sources of supply.

To date, assessments of the hardening manual have been conducted entirely by Scientific Service personnel. The results have been sufficiently encouraging that the manuals are soon to be tested by uninitiated plant personnel in industry. These onsite evaluations by industry are the major objective of the Phase II effort, recently started. A Phase III effort will incorporate the information gained in the testing phase into a revised and updated edition.

ABSTRACT

This report presents a prototype industrial hardening manual, developed by Scientific Service, Inc., to reduce industrial vulnerability to natural and nuclear disasters. The multi-booklet manual is the output from the first phase of a multi-phased program to provide both planned and expedient measures that may be implemented by industry to preserve production capability in a crisis.

The manual provides guidance to the uninitiated in the form of procedures for assessing vulnerabilities, defining hardening options, and evaluating hardening alternatives.

ACKNOWLEDGEMENTS

This report and the research work which it describes are the result of the combined efforts and talents of a large number of people. The authors wish to express their appreciation to all the participants, especially the following:

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Michael A. Pachuta, Defense Civil Preparedness Agency
George Sisson, Defense Civil Preparedness Agency
Larue Wilton, Scientific Service, Inc.

INTRODUCTION

This report presents the results of the first phase of a multi-phase program to develop an Industrial Hardening Manual. The objective of this first phase was twofold: 1) to develop a methodology for increasing industry's capability to survive a nuclear attack and to accelerate post-attack return to production; and 2) to present this methodology in a prototype industrial hardening manual. Phase II, now underway, will test this manual in industry to evaluate its performance and gather data. During Phase II, the results of this testing phase will be used to revise and upgrade the manual. This work was conducted by Scientific Service, Inc. under Defense Civil Preparedness Agency Contract No. DCPA01-77-C-0228, Work Unit No. 1124C.

To achieve the initial goal required that one or more workable strategies be applied and developed which could enable industry to respond to a national emergency to mitigate damaging effects of nuclear weapons. To find workable strategies it was necessary to examine a variety of possible options and select from them those that were viable. The conclusion reached was that preparation and planning, and dispersion and strengthening of facilities are the principal options that industry might apply to reduce vulnerability to attack. Preparation and planning should also consider the opportunity to ensure survival through two other options — redundancy and a fallback position. Redundancy requires dispersion of the key redundant items, to be practical. A fallback position involves retreat to a lower technology, hence lower output and, possibly, lower quality products.

In consideration of historical events, at least one viable strategy has to be implementable quickly, on short notice. At present, this short-term option appears to be the most demanding in regard to development of a manual. It is anticipated that long-range options may evolve as spinoffs

from expanding on short-term options; that is, initiating planning at an early date presents the opportunity to bring more resources to bear on the problem including time for organizing and preparing for action.

The hardening process itself comprises a combination of strategies that are fully compatible with virtually any defense posture: stay-put, crisis relocation (and relocation planning), etc. Implementation strategies, of course, vary in degree with the national defense posture and with planning and implementation time allocated. The manual is expected to be versatile enough for all contingencies.

METHODS

The approach taken necessarily involved a combination of deductive and inductive analyses. A search of the literature provided a paucity of pertinent data on plant equipment vulnerabilities. Available data were augmented by vulnerabilities calculated inhouse, using experience and expertise in the field of engineering and mechanics gained from laboratory and field studies of nuclear weapons effects and hazards assessment. Upgraded vulnerabilities were determined in the same way. To determine the subjects that should be addressed, logical sequences of events were examined assuming constraints typical of an emergency or crisis environment.

To help with elimination of impractical responses, serve as a devil's advocate, and provide the viewpoint of the uninitiated industrial end-user, a former plant engineer was assigned permanently to the project. Additional concessions to ensure practicality of the final product included plant site visits during the period the manual was assembled, and assignment of sections of the manual to different authors, with review by other authors. Draft copies were provided to industrialists and to the Defense Civil Preparedness Agency for review, and the manual revised accordingly.

The hardening manual review and revision process is not yet complete and will not be until serious efforts at hardening are carried out in a number of industrial plants, both on paper and physically. Some of these exercises are in process at this time, and the outcome will be used to update the manual. In addition, the booklet approach will simplify the incorporation of results of studies now being conducted at SSI (or elsewhere) dealing with specialized areas. As an example, the booklet method will enable other booklets to be added that deal with appropriate disposition of hazardous materials, and with upgrading of shelters in host and plant areas.

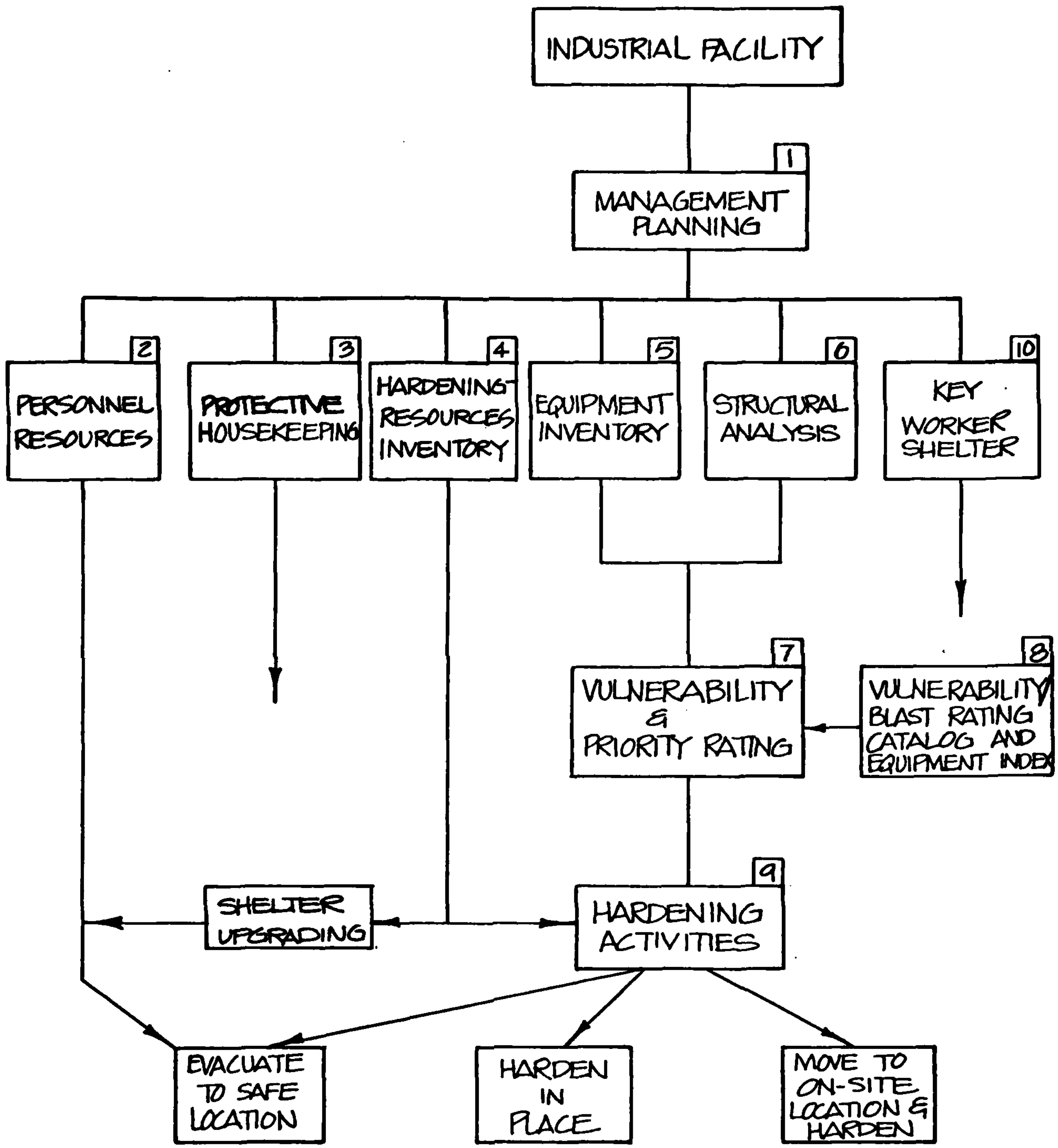


Figure 1. Flow Chart of Industrial Hardening Plan.

DISCUSSION OF RESEARCH ACCOMPLISHED

An important facet of the program is a quantitative assessment of industrial vulnerability before and after applying industrial hardening. The application phase, Phase II, is intended to test and evaluate the capability of the first iteration of the manual to enable industry to reduce vulnerability to nuclear attack.

To facilitate this assessment, the industrial manager has been provided with a system for organizing his thoughts and tasks, which will enable him to rank the priorities for his hardening activities according to specific (but his own) perceptions of relative importance to operations, and replaceability. The procedures will also enable him to keep track of the upgrading in priority achieved, simultaneously. The priority system has been designed to have a one-to-one correspondence with the psi overpressure upgrading, so that the latter is defined as well. Thus, the Phase II application study conducted by industrial users will result in defining priorities for upgrading activities before and after hardening (i.e., it will define priority changes) that will be numerically identical with the overpressure upgrading.

The selected approach makes it theoretically possible to draw a preliminary relationship between industrial upgrading achieved and the corresponding reduction in effectiveness of a given attack, by comparing relative areas for constant damage before and after hardening. An alternative comparison might be to calculate the increase in number and/or size of weapons required to raise the overpressure to the upgraded level of industry within each target area. But this cannot be done at all without an estimate of what the targeting might be, while the former relationship enables the targeting question to be bypassed, at least initially. A rough preliminary assessment of cost and performance is discussed in the next section.

DATA

Onsite dry runs using the industrial hardening manual have been conducted at three plants: a foundry, a light metal fabricating shop, and a transformer manufacturing facility. These dry runs were conducted by SSI personnel with two objectives in mind; i.e., to evaluate the clarity and general practicability of the booklets, and to determine the effectiveness of the approach.

For each of these initial dry runs, no physical actions were taken; rather, information was gathered regarding what actions might be best to take. Thereafter, an estimate was made of the time required to carry out these operations, assuming that they would be initiated with most of the normal manpower complement of the plant the first day and gradually tapering off, due to planned relocation efforts, to just a few individuals by the third day. Notes taken at the same time regarding the practicality and clarity of directions were used to revise booklets, accordingly, at a later time.

The manual effectiveness assessment and the vulnerability priority rating and hardening decision analyses for the three plants were conducted at SSI. The equipment and hardening resources inventory data were gathered exactly as outlined in the booklets. The protective housekeeping booklet, however, is premised on initiating action immediately, so that for the initial evaluation the data had to be acquired regarding disposition of inventories of materials, work in progress, etc. Using experienced personnel familiar with the concepts, SSI gathered all the data at the three plants in less than 20 man-hours total. Decision analyses took 40 man-hours for the foundry, 20 man-hours for the transformer plant, and 2 hours for the light metal fabricating shop. Man-hour estimates to complete the hardening based on resources on hand indicated ample time to achieve the

end result scheduled when experienced personnel made the assessment.

At the foundry, this assessment indicated the plant vulnerability was raised from 2 psi to 8 psi. At the transformer plant, vulnerability was raised from 2 psi to 17 psi. At the small metal fabricating shop, all the equipment would have been moved to the host area at the end of Day One. Moreover, if six or eight return trips could be made, all supplies could be moved to the host area on Day Two. Traffic conditions could well preclude the latter activity, however; and in any case, the equipment would be the major priority for resuming operations.

In these plants little was scheduled to be done to structures. However, the major threat to industrial equipment is from collapse of the light-steel-framed metal-paneled buildings which are typical of a large percentage of industrial structures. Consequently, these structures will be demolished at a few psi, and in general, recovery operations will involve considerable time spent either clearing off collapsed structures, or extricating equipment to put into operation elsewhere. The paper exercises conducted for this study at the three plants involved protecting key equipment by precluding damage from the collapsing structures.

At this stage of the program, the three plant studies indicate that industrial hardening offers significant potential for shifting industrial vulnerability to higher overpressure levels. If all plants could be raised from a vulnerability level of 2 psi (typically, the collapse pressure for the buildings) to 4 psi, then the relative areas subjected to these two overpressures is a measure of damage avoided; that is, the area subjected to 4 psi is only 38% of the area subjected to 2 psi, and the area reaching the new damage level is 62% less than before. If the vulnerability could generally be raised from 2 psi to 8 psi (as appears feasible so far), then the area of damage is reduced by 84% (i.e., to 16% of the original area). If industry were uniformly distributed in the risk area, then according to these calculations, the portion of industry saved from serious damage by hardening (to 4 psi, or to 8 psi) would be 62% and

84%, respectively. However considered, the impact on survival and recovery of industry appears to be significant.

Of course, this is a somewhat simplified analysis of benefits. Moreover, data from a large number of plants (20 to 30) will be needed to arrive at a statistically significant average upgrading per plant. With the data available at present, a preliminary assessment was made of costs vs. benefits. For the costs, a rough initial estimate of the labor cost to conduct the planning and preparation for industrial hardening was made using the SSI experience at the three plants. Assuming the uninitiated would take several times as long as professionals and that the effort might be related to plant size (as determined by the number of employees), the estimated cost is around one-half hour per employee. At one hour per employed person, the planning time required nationwide could run about 70 million man-hours and cost, perhaps, between $350 million and $700 million. Compared with a potential for saving a significant portion of industry, this advance planning cost looks inexpensive.

Better, hard data on industry planning cost will be available after the Phase II studies. Whatever the costs, advance planning would more than pay for itself in better results that could be achieved in a national crisis. Moreover, as an incentive to planning now, it is quite conceivable that emergency procedures developed might more than pay for themselves in solutions to other emergency problems; e.g., earthquakes, fires, hurricanes, rolling blackouts, etc., that might occur from time to time.

CONCLUSIONS AND RECOMMENDATIONS

The effort completed to date, and the material presented herein, imply considerable success so far in developing a practical course of action for reducing industry vulnerability to nuclear attack, and it can be implemented on short notice (72 hours). It remains, now, only to be seen if the significant upgrading achieved at three plants (on paper) in three dry runs conducted by individuals with many years in the weapons effects field can be duplicated by the uninitiated and in general. This will be a major facet of the Phase II program now underway.

Two items will also receive special attention during Phase II. Because the major risk to industrial equipment is from collateral damage that can occur with collapse of the structure sheltering the equipment, a generic solution to this problem is desirable. Many industrial buildings are steel-frame-and-panel structures which might possibly be rapidly disassembled. This is deserving of some time-and-motion, cost-and-benefit consideration. The other item of special interest is the role played by work-in-progress on the speed of post-attack recovery. A trade-off analysis, comparing the effect on recovery of hardening raw materials versus hardening work-in-progress, is needed. Raw materials may be easier to harden to higher overpressures than work-in-progress, principally because of packaging and storage differences. On the other hand, if all work "in the pipeline" were abandoned, it might be a very long time before industry got rolling again. This would be particularly true of industries dependent on the output of other industries for input to their production.

It is anticipated that the Phase II effort, when completed, will result in additional recommendations relating to practical applications of the manual by industry, to complement the preliminary assessment discussed

here. As Phase II data, and data from other ongoing DCPA and DNA programs become available, Phase III — revision of the manual — will be undertaken.

It should be noted that, even after completion of Phase II, the assessment of the implications of industrial hardening will have a long way to go. For example, the testing phase will involve seven or eight plants, some of which will be subjected exclusively to paper analyses, some of which will physically implement some part of the manual, and one of which will go through the entire implementation. To provide data that will be conclusive about even one single industry generally, it would be desirable to have a statistically significant sample of that industry (preferably 20 to 30 plants) physically implement at least some part of the manual, as well as have as many of those plants as possible implement all of it.

Moreover, there are many different industries and each will probably require some assurance of demonstrative results before contemplating a serious planning effort. This will probably require statistical data from one or two dozen plants in each of a dozen different industries. The effort to provide such evidence does not seem unreasonable despite the significant cost; it is unlikely to exceed several percent of the industrial planning effort that it is hoped to foster.

In the effort to accumulate hard data, more than physical hardening exercises should be conducted. For example, information should be developed on how to stiffen and harden groups or clumps of equipment using banding, wedging, and anchoring techniques as means to resist nuclear blast waves and drag forces. Both laboratory and field experiments could be used to develop and test such techniques and to provide valuable insight into expedient means to provide quick-fix hardening alternatives. In the final analysis, experimental data will be desirable for validating the calculated levels of hardening achieved.

Appendix D

SOIL TEST PROGRAM

USING 1MW SOLAR FURNACE

By: John Cockayne
Science Applications, Inc.

RESUME OF WINTER SOIL TEST PROGRAM AT 1MW SOLAR FURNACE

- OBJECTIVES
- DESCRIPTION
- DATA COLLECTION
- RESULTS
- EARLY OBSERVATIONS
- IMPLICATIONS FOR FURTHER PROGRAMS

WINTER SOIL TEST PROGRAM AT 1MW SOLAR FURNACE

- OBJECTIVES -

- SOIL TEST DATA
  - PARAMETRICALLY SELECTED SAMPLES
  - SPECIFIC NEVADA VALLEY SOILS
  - VEGETATION
  - MAN MADE SURFACES
- APPARATUS AND INSTRUMENTATION CHECKOUT
  - HIGH FLUX EXPOSURES
  - TEST ENVIRONMENT OPERATION
- SPECIAL LIGHT ATTENUATION/SCATTERING EXPERIMENT

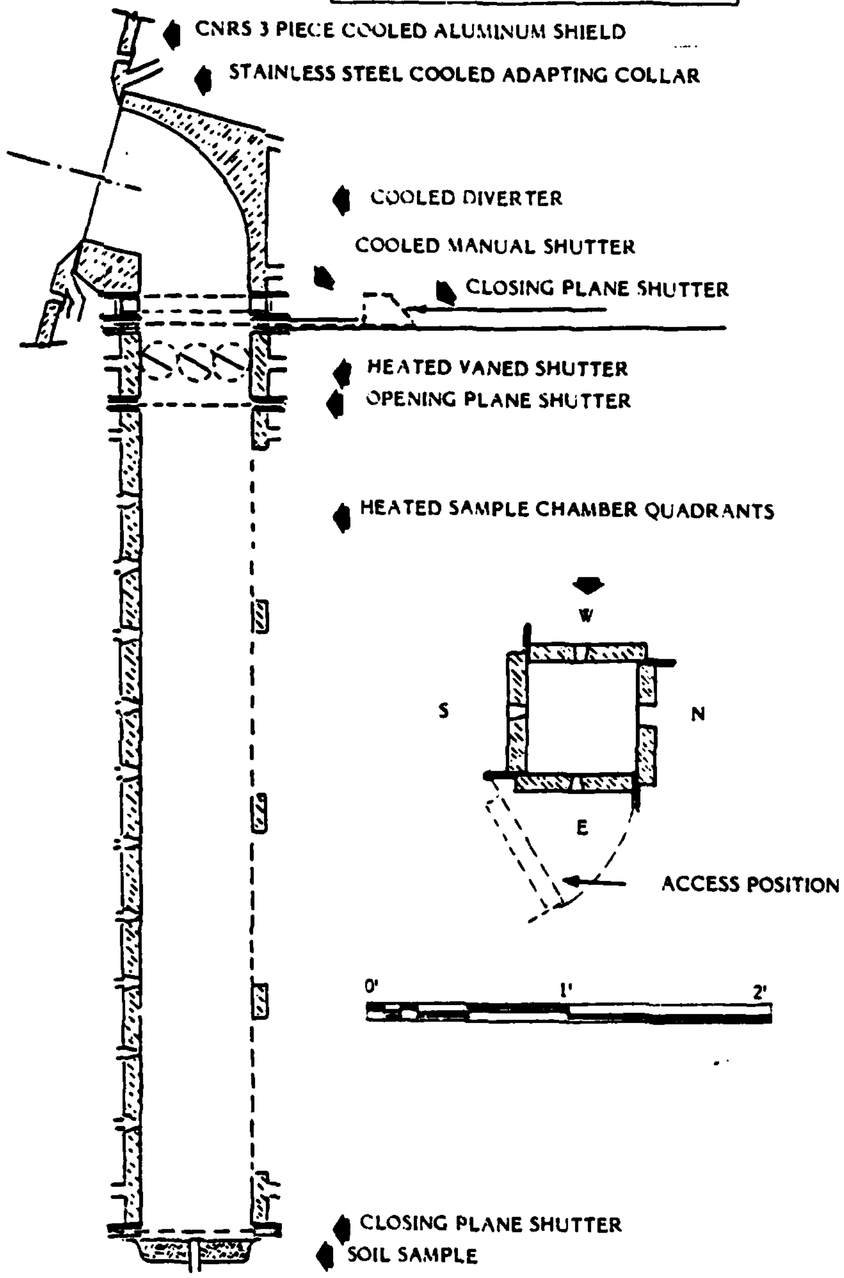
WINTER SOIL TEST PROGRAM AT 1MW SOLAR FURNACE
- DESCRIPTION -

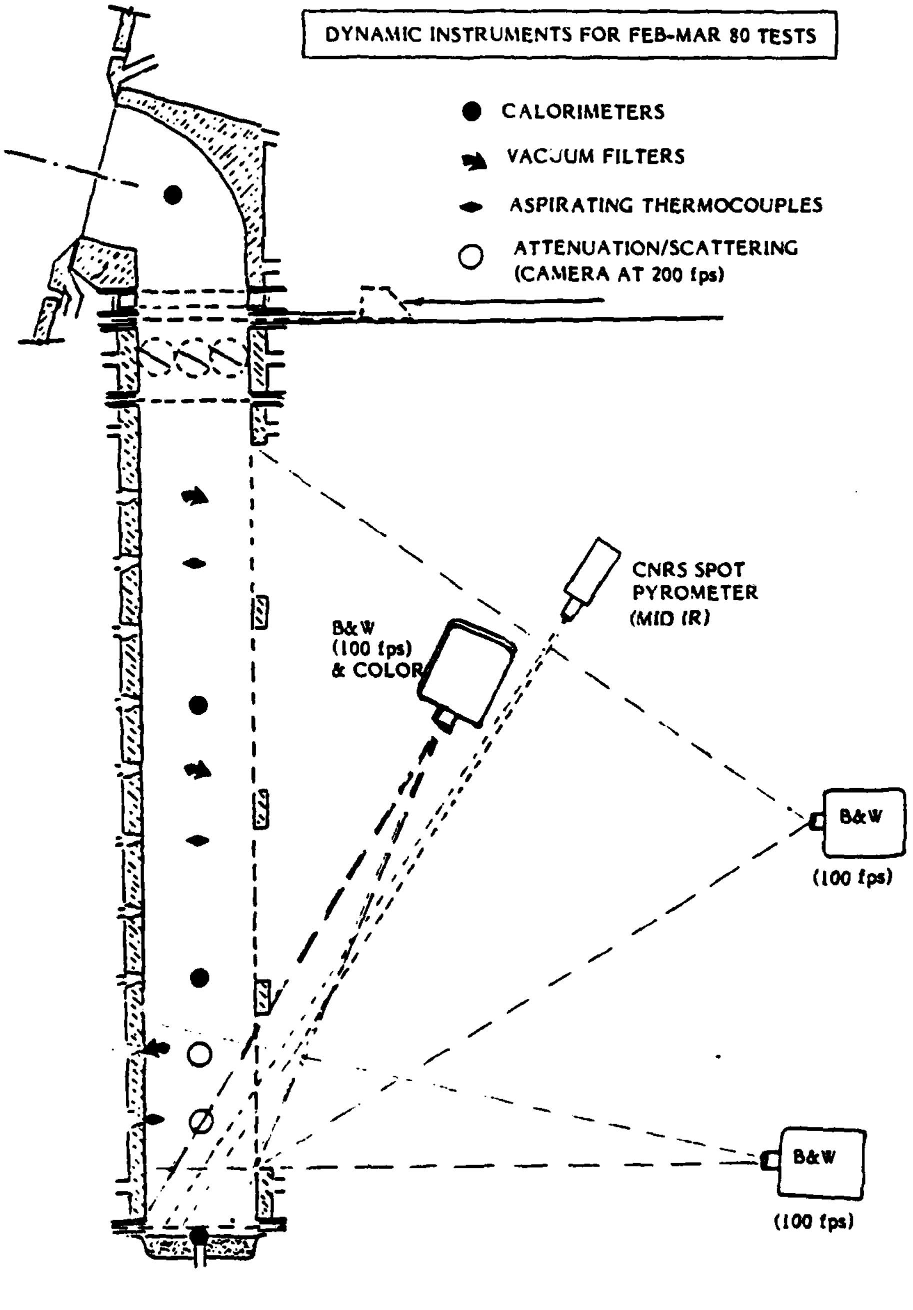
- 18 FEB - 7 MAR 1980 - CNRS 1MW FURNACE, FONT-ROMEU, FRANCE
  CNRS - GITEES - DRI - SAI
- EQUIVALENT OF APPROXIMATELY 6 FULL TEST DAYS
- 152 TEST RUNS
  - 1/8 TO 5 SECONDS
  - 41% TO 100% AVAILABLE FLUX
  - 18 PARAMETRIC SOILS (38 RUNS)
  - 45 NEVADA VALLEY SOILS (46 RUNS UNDISTURBED, 11 RUNS DISTURBED)
  - VEGETATION (9 RUNS), SNOW (1 RUN)
  - 5 MAN MADE SURFACES (5 RUNS)
  - CRUSHED ROCK (COMBINED BY SIEVE SIZES) (11 RUNS)
  - SPECIAL EQUIPMENT/INSTRUMENT CALIBRATIONS (31 RUNS)

TEST APPARATUS DESIGN OBJECTIVES

- MAXIMUM FLUX ON A LARGE AREA BELOW A 4 FOOT COLUMN OF AIR
  - -- CHOICE OF CNRS FURNACE
  - -- SMALL AREA VERSUS LOSS IN TRANSIT
  - -- FLUX COLLECTION AND DIVERSION
  - -- PULSE SHAPING
  - -- SUPPORT INSTRUMENTATION
- SURVIVAL
  - -- COOLING
  - -- MATERIAL
- MINIMUM CYCLE TIME
  - -- ACCESS
  - -- TEST TEAM
  - -- CNRS PERSONNEL/SHOPS/EQUIPMENT

APPARATUS FOR FEB-MAR 80 TESTS




DYNAMIC INSTRUMENTS FOR FEB-MAR 80 TESTS
CALORIMETERS
VACUUM FILTERS
ASPIRATING THERMOCOUPLES
ATTENUATION/SCATTERING
(CAMERA AT 200 fps)
CNRS SPOT
PYROMETER
(MID IR)
B&W
(100 fps)
& COLOR
B&W
(100 fps)
B&W
(100 fps)

WINTER SOIL TEST PROGRAM AT 1 MW SOLAR FURNACE
DATA COLLECTION - STATIC MEANS

-- MOISTURE CONTENT

-- PRE AND POST RUN WEIGHT

-- PRE AND POST RUN SURFACE PHOTOGRAPHS

-- PRE AND POST RUN SURFACE PHOTOMETRY

-- POST TEST CHAMBER WIPE DOWN

-- MICROSCOPIC ANALYSIS AND COMPARISON OF AFFECTED SOIL GRAINS

-- MECHANICAL SOIL ANALYSIS SIEVE SIZE DISTRIBUTIONS, COMPOSITION, PHYSICAL PROPERTIES

WINTER SOIL TEST PROGRAM AT 1 MW SOLAR FURNACE
DATA COLLECTION - DYNAMIC MEANS

- PHOTOGRAPHIC
  - -- FULL HEIGHT (B&W)
  - -- ACROSS SURFACE (B&W)
  - -- DOWN ON SURFACE (B&W AND COLOR)
  - -- ATTENUATION AND SCATTERING AT 6" - 10"
- ELECTRONIC
  - -- CALORIMETRY (SOIL SURFACE UP TO DIVERTER)
  - -- AIR TEMPERATURE (UP TO 3 DIFFERENT LEVELS)
  - -- SOIL SURFACE PYROMETRY
  - -- INSOLATION
- SAMPLING BY SUCTION OF CHAMBER GAS/PARTICLE MIXTURE THROUGH FILTER

RESULTS

- APPARATUS CONFIGURATION
  - -- ACCEPTANCE ANGLE/FLUX RELATIONSHIPS
  - -- UPPER CHAMBER HEATING
  - -- SHUTTER OPERATION
- SURVIVAL
  - -- HORIZONTAL COOLED SHUTTER
  - -- STAINLESS STEEL COLLAR
  - -- SOLDERED JOINTS
  - -- ETHYLENE GLYCOL AS COOLANT/HEATING MEDIUM
  - -- UNCOOLED SURFACES
    - ALUMINUM COLLAR
    - PLANE SHUTTER BLADES
    - VANED SHUTTER BLADES
- 152 RUNS IN APPROXIMATELY 6 SUN DAYS
  - -- MAXIMUM DOWN TIME FOR EQUIPMENT -- 1 HOUR
  - -- 10 REPAIRS OR FORCED RECONFIGURATIONS

WINTER SOIL TEST PROGRAM AT 1 MW SOLAR FURNACE
- EARLY OBSERVATIONS -

- REACTION OF SURFACE PARTICLES
  - -- PARTICLES AFFECTED (DISTRIBUTION OF FINES)
  - -- COLOR CHANGE
  - -- MELTING
  - -- COALESCING
  - -- REPEATED CYCLE
- PROTECTION OF SURFACE BY VEGETATION
- HIGH UPPER CHAMBER FLUX - DIRECTIONALITY OF APPARATUS
- DUST VERSUS WATER VAPOR - MISLEADING VISIBLE EFFECTS?
- LAYER HEIGHT UNCERTAIN
  - -- PARTICLES ON DIVERTER
  - -- APPARENT GRADIENT

WINTER SOIL TEST PROGRAM AT 1 MW SOLAR FURNACE
- IMPLICATIONS FOR NEXT PROGRAM -

- APPARATUS
  - -- REDUCED WIDTH F.O.V. AND INCREASED AREA OF ACCEPTANCE DESIRABLE
  - -- ALTERNATIVE PULSE SHAPING
  - -- DIFFERENT DUST DENSITY/SOUND VELOCITY SENSING
  - -- VIEWPORT QUADRANT WITH SOIL LEVEL VIEW
  - -- BACK-UP QUADRANTS
  - -- READIER FLEXIBILITY IN SHIELD SUPPORT
- CONTROLS
  - -- INDEPENDENT ELECTRIC CIRCUITS
  - -- CAPABILITY FOR MANUAL OPERATION

WINTER SOIL TEST PROGRAM AT 1 MW SOLAR FURNACE - IMPLICATIONS (CONTINUED)

- INSTRUMENTS
  - -- STRONGER/SILVERPLATED THERMOCOUPLE ASSEMBLIES
  - -- AIR BACKFLUSH CAPABILITY FOR THERMOCOUPLES
  - -- SEPARATED VACUUM SAMPLING VALUES
- RECORDING
  - -- COMPUTER WITH IMMEDIATE, CALIBRATED GRAPHIC PRINTOUT

Appendix E

ESTIMATING EXPLOSION YIELD FROM CHAR DEPTH

This material was assembled by C. P. Butler who has had a long term interest in the subject. The historical material is derived from early work done at the U.S. Naval Radiological Defense Laboratory (NRDL) under Armed Forces Special Weapons Project (APSWP) Sponsorship. In this appendix these historical data are compared with data recently acquired by LATA using the TRS simulation.

Char Depth and Weapon Yield

From the time when nuclear testing began at Trinity, efforts have been made to simplify field dianostics to the point where--for example--simple, passive devices could be placed on a pole and left unattended to record characteristics of a nuclear explosion. The ideal passive thermal gage has not been devised yet. Little progress has been made in this direction since the 1950s except for the recent development of passive fluence gages by LATA. Another approach is to deduce explosion yield and the resulting thermal environment from its effects on target elements. In principle, knowing enough about material responses, one should be able to reconstruct the main events in any future, uninstrumented nuclear explosion, much as an arson investigator is trained to do, by reading telltale signs in the form of previously calibrated effects. Thermal damage to the exposed surfaces of wood, ubiquitous as the material is in both urban and rural settings, has held our interest for many years with the prospect of providing such a postevent diagnostic.

One of the effects of a nuclear detonation in the atmosphere is a permanent record of the thermal pulse in the charred remains of wood. It was soon evident that the amount of this charring was related to the energy absorbed and thus depended on the distance from the point of detonation and the size of the fire ball which in turn depends on weapon yield. Moreover, because solid wood will not sustain combustion without

an external source of convective or radiant energy, charring might also be influenced by the thermal pulse, i.e., the irradiance or flux versus time.

An experimental program was conducted at NRDL to relate the depth of char to the weapon yield and the distance. The primary purpose was to provide a simple method to determine weapon yield from measurements of char depth and distance only.

The first step was to measure char depths in solid wood produced by high thermal flux levels from a carbon arc that simulated the thermal pulse from a nuclear weapon. The result of some of this work is shown in Figure E-1. It will be noticed that confidence levels are included. This was necessary because a natural product like wood is not homogeneous and varies considerably from one piece of lumber to the next, and from tree to tree. While distances of a tenth of a millimeter are difficult to replicate, it can be seen that such small differences are real.

The results of laboratory simulated thermal radiation pulses from various yields, distances, peak fluxes and fluences are combined in a single nomograph in Figure E-2. It can be seen that any two parameters can be used to estimate the other two.

Data Reduction on Char Depth

Fluence values for Shot 1, July 11, 1979, were taken from Figure 6.1 and from Figure 6.4 for Shot 1A, July 31, 1979, as found in the Draft Report of LATA-DNA-01-01. Arithmetic means were read from the two values given for each station. These are assembled in Table E-1.

The last column in this table gives the depth of char for each station and both shots. Different char depths at some stations were values read in different locations on the wood panels. It is assumed that the wood panels were located in approximately the same position as the instruments used to make the fluence observations.

Figure E-3 shows a plot of fluence values for Shot 1 and 1A and depths of char. It will be apparent that the data of 1979 is about

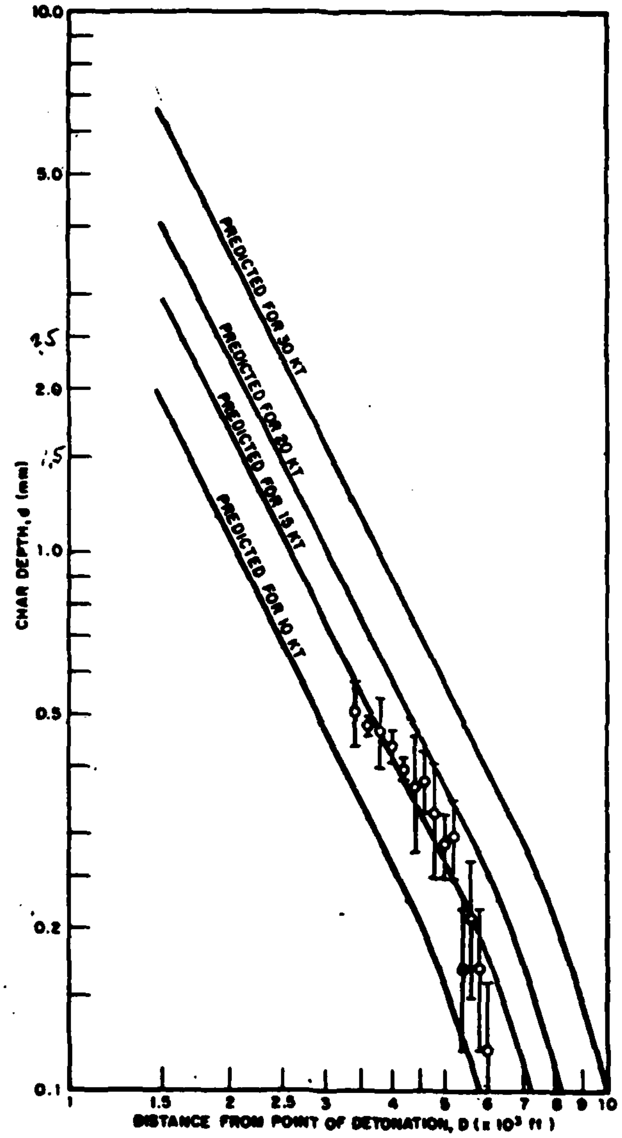


Fig. E-1 Char Depth as a Function of Distance From Point of Detonation Compared to Predicted Curves for Various Weapon Yields

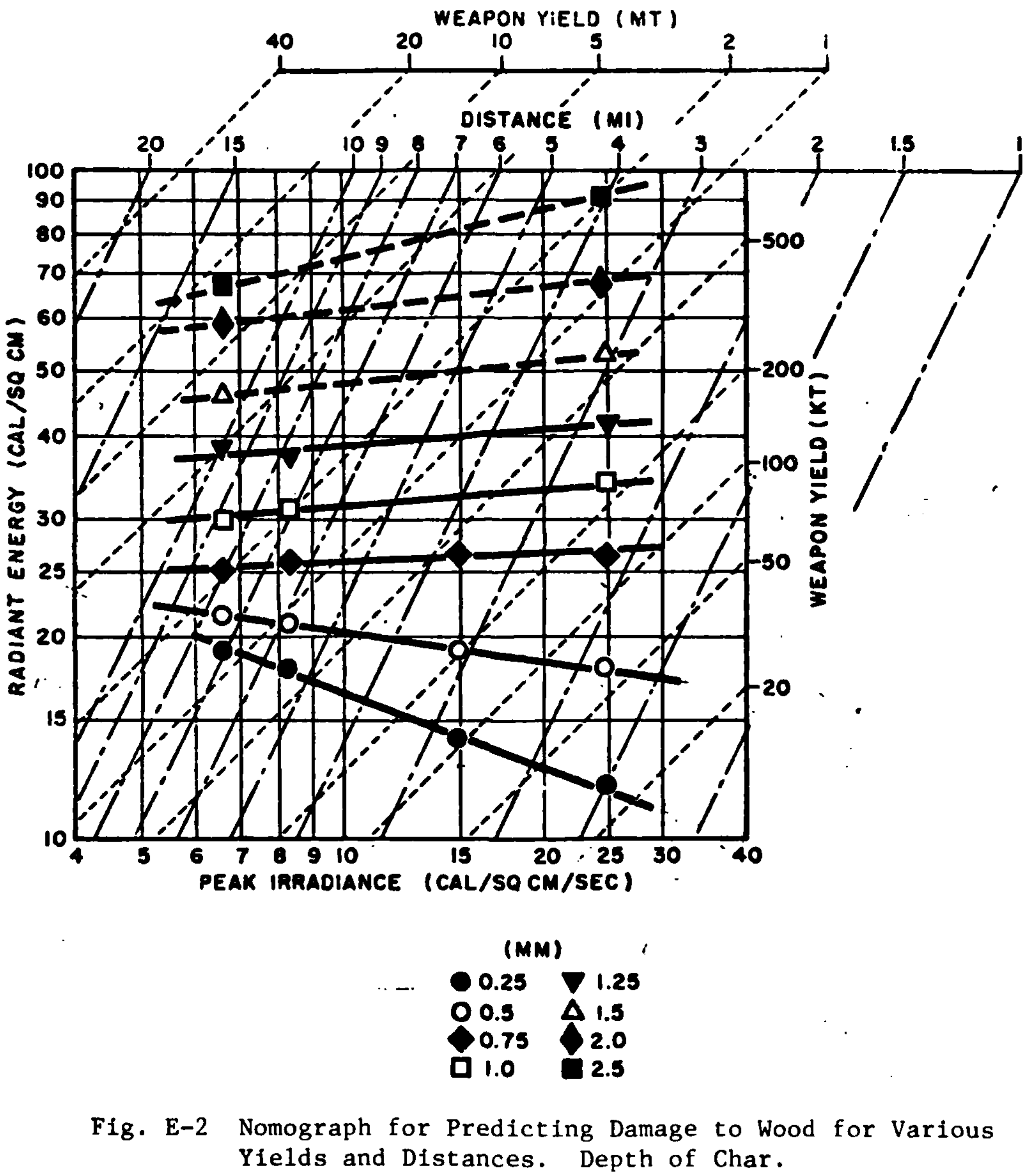


Fig. E-2 Nomograph for Predicting Damage to Wood for Various Yields and Distances. Depth of Char.

LARGE-SCALE THERMAL... TESTS DCPA

TABLE E.1

STATION NUMBER	FLUENCE Cal cm^{-2}	PEAK FLUX CAL CM^{-2} SEC^{-1}	CHAR DEPTHS mm
SHOT 1 JULY 11 1979			
2	8.5	15	0.11
1	15.5	27	—
3	17.5	30	0.29 0.30
4	22.5	39	0.44 0.37 0.38 0.30
SHOT 1A JULY 31 1979			
2	9.0	6.3	0.025 0.018
1	16.8	11.6	0.14 .011 013 .014
3	18.8	13.0	0.30 .027 0.25
4	18.8	13.0	0.30 .026

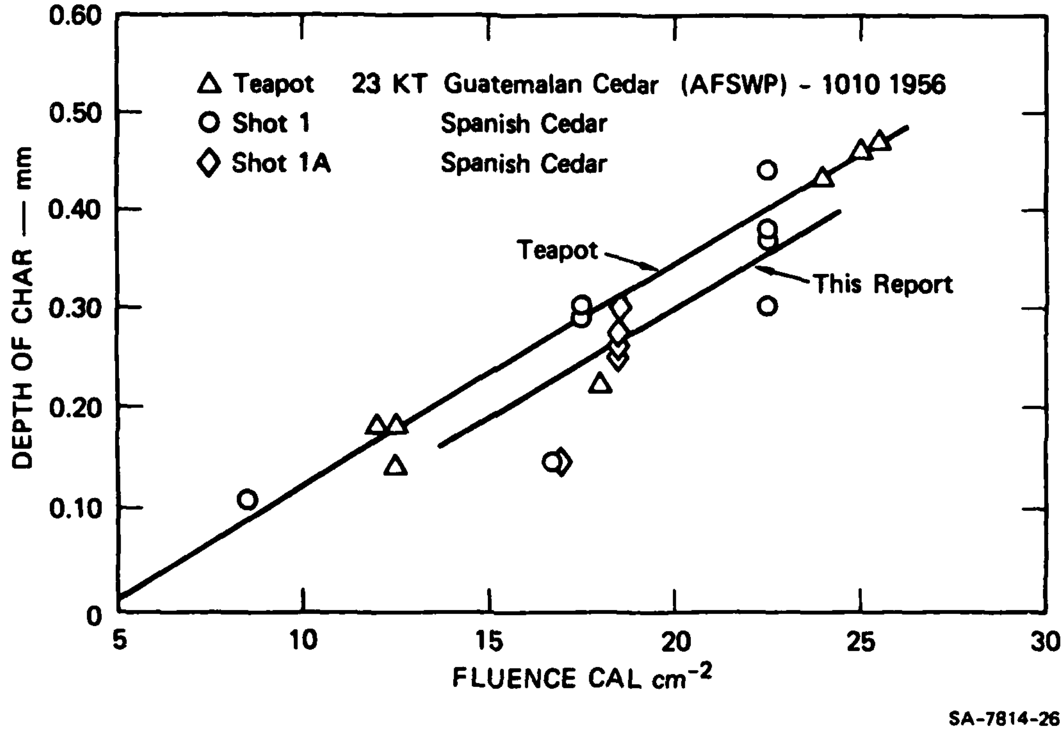


FIGURE E-3 EMPIRICAL DEPTH-OF-CHAR/FLUENCE RELATIONSHIP

0.05mm less than that given for Teapot in 1956. The scatter of the data does not permit a firm conclusion on this point.

Two curves are given in the LATA report for the pulse shape of each shot. It is assumed that the pulse shape at each station is identical to that shown.

It is stated that the asymptotic calorimeters are "unreliable," but it is assumed here that this statement refers to the calibration of the instrument in terms of watts cm^{-2} mV^{-1}, and not to its time constant, that the pulse shape is correct and hence the area under the curve is the fluence for each station.* Values of thermal fluence were calculated from planimeter readings and are given along with values of peak flux in Table E-1.

Conclusions

Reasonably accurate fluence values can be deduced from char depth measurements in wood. Although no formal attempt was made to evaluate confidence limits, one can probably expect to estimate fluences to within ± 10 to 20% using woods that are inherently uniform grained. Moreover, the results appear to be insensitive to the rate at which the radiant energy is delivered; the data for nuclear weapons is closely comparable to the TRS exposures, but more revealing is the fact that these data are only about a factor of two different from the arson investigator's rule of thumb (1/8 inch depth of char in 5 minutes) even though the heat fluxes are different by at least an order of magnitude.

This remarkable insensitivity to heat flux implies that char depth is a poor indicator , by itself, of thermal pulse duration and, therefore, of weapon yield. And while the estimates of fluence can be combined with a knowledge of the corresponding distances from the burst point to infer yields, as was done at Teapot, even this device requires assumptions about atmospheric transmission and dust obscuration to be made, which

*But more importantly, that the ratio of peak flux to total fluence is correct and applies to all exposures, irrespective of distance.

could thoroughly invalidate the results. The Teapot depth of char data estimated the energy yield to be 17 ± 5 kT; the radiochemical estimate was 23 kT, a difference of only 30%, but under circumstances of good, and well known, transmission.

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BLAST/FIRE INTERACTIONS

Asilomar Conference
DETACHABLE SUMMARY

Proceedings of the Conference

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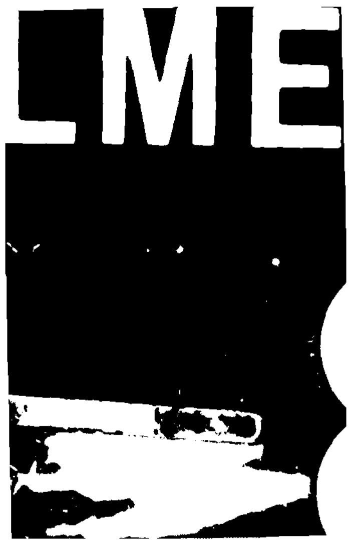
SUMMARY

Fire from a nuclear weapons attack is a direct threat to the population of the United States and an indirect, long term threat to national survival, because fire can destroy the shelter, sustaining resources, and industrial machinery essential to economic recovery. Unresolved questions about interaction between blast effects and fire effects preclude any reliable estimate of the incendiary outcome of a nuclear attack on the United States. As such, these uncertainties are a major obstacle to defense planning and they interface with national security policymaking at the highest levels.

In an effort to rectify the technical deficiencies in predicting the incendiary outcome of a nuclear attack and to formulate a well-directed program of research, the Defense Civil Preparedness Agency contracted with SRI International in 1978 and again in 1979 to convene a conference of authorities on fire and blast, structural response, and related technologies. This report covers the proceedings of the third in the series of conferences, now under the sponsorship of the Federal Emergency Management Agency (FEMA) and describes the early activities of the DCPA/FEMA program of (nominal) 5-year duration, whose objective is to achieve an analytical method for reliably predicting fire behavior and incendiary outcome. Some substantive progress is reported.

Within a framework of crisis relocation planning, several questions need to be resolved, and several decisions need to be made promptly. A working concept of critical resources is paramount in realistic thinking about the fire problem and countermeasures to mitigate the threat. To avoid delay in strategic planning, this guidance should be developed, at least in preliminary form during the upcoming federal fiscal year (i.e., FY81).

A comparison of the recommended and actual funding to date shows that the program is getting under way at less than 60% of the original goal as urged in the 1978 conference. Accordingly, in assembling the revised FY80 program during the 1979 conference, a somewhat more austere program was acknowledged as a more realistic goal. While the austere plan continues to appear the most realistic to the 1980 conferees, in recognition of the always present possibility that national security funding might be increased, this year's program plans are presented in contingency format. As before, however, the focus is on the vulnerability of critical facilities and resources and the threats to survival of key individuals. This program, therefore, remains consistent with the broad objectives of the program as laid down in the first conference in 1978.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